PROCEEDINGS

PATT 42

The 42nd Pupils' Attitudes Towards Technology Conference

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The PATT42 Conference was jointly organized by the Université du Québec en Abitibi-Témiscamingue (UQAT), Université de Sherbrooke, Lille University, Université du Québec à Montréal (UQAM), and the Haute École Pédagogique de Fribourg, in partnership with the CRIDiD Research Center.

The success of this event reflects the dedication, commitment, and hard work of the organizing committee, whose efforts ensured a stimulating academic program and a welcoming environment for all participants.

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A Primer on the use of Q Methodology for Investigating Subjective Views and Beliefs in Design, Technology and/or Engineering Education Research

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ABSTRACT

As research in technology, engineering, and/or design education continues to grow globally, ensuring methodological rigor and trustworthiness is increasingly vital. A 2011 UK expert review found the epistemological foundations of design and technology weaker than those of more established STEM subjects, underscoring the need for robust scholarship to justify newer disciplines. Over the past 30 years, TED subjects have evolved from gendered, craft-based curricula to inclusive, future-focused education preparing learners for a technologically advanced world. This paper introduces Q Methodology within the context of TED education research. Originating in psychology, Q Methodology is a pragmatic, seven-stage approach for exploring subjective beliefs through qualitative data and factor analysis. It involves defining a range of views, refining them into statements, selecting participants, sorting statements, conducting post-sort interviews, analysing factors, and interpreting groupings of shared perspectives. Unlike methods that seek consensus, Q Methodology reveals a plurality of views, making it especially valuable in diverse educational contexts while preserving the integrity and plurality of participants' beliefs, recognising both consensus and distinguishing views.

Keywords: *plurality, pragmatism, primer, Q Methodology, subjectivity.*

1. INTRODUCTION

1.1 Contextualising Subjectivity in Technology, Engineering and Design Education

The global community of educators and researchers in technology, engineering, and/or design (TED) education continues to expand and mature. Consequently, the methods employed within this field require increasing rigour and trustworthiness. Research in TED education often addresses complex, multifaceted phenomena, including human perspectives, opinions, and beliefs (Desing & Kajfez, 2020). Understanding these subjective dimensions is crucial for comprehending how individuals perceive educational experiences, new technologies, and pedagogical approaches (Hagan & Williams, 2016). Subjectivity conventionally considered a challenge in educational research due to its perceived lack of objectivity, gains increasing recognition for its importance in understanding teacher expertise and student learning processes.

An expert review in the UK for the Department for Education (DfE, 2011) identified weaknesses in the epistemological foundations of design and technology (D&T) compared to more established STEM subjects like mathematics and science. This, along with other critiques of the subject such as McGimpsey (2011) and Miller (2011), assessment underscored the necessity for robust, transparent research and scholarship to validate subjects that lack historical precedence and tacit acceptance. The application of well-established, yet adaptable, research approaches become imperative to strengthen the academic standing and instructional efficacy of TED education.

1.2 Pragmatism, TED Educational Research and Q Methodology

Pragmatism aligns closely with Q methodology as both prioritise practical understanding and the meaningful interpretation of subjective experiences (Gillespie, Glăveanu & de Saint Laurent, 2024; Watts & Stenner, 2012). Q methodology, grounded in a pragmatic philosophy, seeks to reveal patterns of thought by emphasising the usefulness of perspectives rather than their objective truth. This approach facilitates an exploration of diverse viewpoints within TED education, enabling researchers to address complex, real-world issues by focusing on how individuals make sense of their experiences and beliefs in context. Consequently, pragmatism provides a philosophical foundation that supports the flexible and interpretive nature of Q studies. Relatively few Q methodology studies have been conducted within the field of TED education. For example, in the *International Journal of Technology and Design Education* (arguably the leading journal in the field) there are four articles published that utilise the approach: two of which are by the author of this paper focussing on educators views of the demonstration and a signature pedagogy in D&T (McLain, 2021; McLain, 2018); one on sciences teachers' views on the nature of technology (Yenilmez Turkoglu, Aydin & Es, 2022); and one on design students' perceptions of agency (Guerra et al., 2025). This demonstrates a gap in the research for a methodology that explores and groups diverse views and beliefs, as opposed to presenting a singular answer or solution to a research problem. This paper provides a primer for researchers who wish to use Q methodology in TED education settings.

1.3 Objectives and Structure

This paper introduces Q methodology, contextualising its application within TED educational research. Q methodology offers a distinctive approach to investigating subjective views and beliefs. It originated in psychology and has expanded its use across various disciplines, including education (Desing & Kajfez, 2020). The methodology operates within a pragmatic framework and comprises a seven-stage process. This process gathers qualitative data and analyses the results using factor analysis and interpretative techniques (Desing & Kajfez, 2020). The distinct advantage of Q methodology over other approaches to studying subjectivities resides in its capacity to generate a plurality of views, rather than a single consensus perspective. This feature acknowledges the variety of experiences prevalent in a diverse international subject area like TED

education. It accommodates *micro* (e.g., local context), *meso* (e.g., regional or national), and *macro* (e.g., international) level variations without compromising the meaning or integrity of participants' views or beliefs (Hagan & Williams, 2016). The subsequent sections of this article will first review existing methodological approaches to subjectivity in TED research. Following this, the theoretical and philosophical underpinnings of Q methodology are detailed. A practical guide to the seven-stage Q method process is then presented, alongside critical considerations for study design and implementation. The discussion concludes with an analysis of Q methodology's implications for TED education research, including its value for policy development, curriculum design, and the broader epistemological foundations of the field.

2. THEMATIC OVERVIEW

2.1 The Evolution of Technology, Engineering and Design Education Research

The historical trajectory of TED education reveals a notable shift from vocational training to a broader emphasis on technological literacy and creative problem-solving. Early research in these fields often mirrored a positivist epistemological stance, focusing on measurable outcomes, skill acquisition, and industrial relevance. This approach frequently employed quantitative methods, such as surveys and experimental designs, to assess the efficacy of specific teaching interventions or curricula. The objective was typically to establish generalisable findings regarding skill development and knowledge transfer. As the fields evolved, so too did the epistemological perspectives inform their research. A growing recognition of the social, cultural, and individual dimensions of learning prompted an increased engagement with constructivist and interpretivist paradigms. This shift fostered the adoption of qualitative methods, including interviews, ethnography, and case studies, to explore the nuanced experiences and perceptions of learners and educators. The focus expanded to include understanding how individuals construct meaning from their design and technological experiences, and how their beliefs influence learning processes.

Despite progress, TED education research faces challenges in establishing its full academic legitimacy within the broader educational landscape. This is partly due to the interdisciplinary nature of the field, which draws from engineering, art, social sciences, and education itself. Such interdisciplinarity can sometimes lead to methodological fragmentation or a perception of lacking a singular, coherent research tradition. Furthermore, the emphasis on practical application and innovation in TED can sometimes overshadow the need for rigorous theoretical and empirical investigation. While practical utility remains central, the field requires sophisticated research approaches to articulate its unique contributions and justify its position alongside more theoretically entrenched disciplines. Demonstrating methodological rigour, particularly in capturing complex subjective phenomena, stands as a key means to address these challenges and solidify the field's academic standing.

2.2 Conceptualising Subjectivity: Theoretical Foundations

Subjectivity, within educational contexts, refers to the individual's unique perceptions, interpretations, beliefs, attitudes, and values that shape their understanding of and engagement with learning experiences. These subjective elements are not merely idiosyncratic thoughts; they are often shaped by social, cultural, and personal histories, influencing how individuals interact with curricula, technologies, and their peers. For instance, a student's prior experiences with design thinking or engineering challenges can profoundly affect their motivation and approach to new tasks. Understanding these internal frameworks is essential because they mediate the impact of external pedagogical interventions. Ignoring the subjective landscape risks implementing educational strategies that fail to resonate with learners or address their underlying conceptualisations. Subjective views can encompass a range of perspectives, from how students perceive the relevance of a subject to their self-efficacy in mastering particular skills.

Traditional quantitative approaches, such as large-scale surveys, frequently attempt to measure subjective constructs using Likert scales or similar closed-ended questions (Reutzel, 2013). While these methods provide broad statistical insights and allow for generalisation to larger populations, they can sometimes oversimplify complex individual perspectives, forcing them into predefined categories (Vecchio et al., 2020). For example, a survey might reveal that 75% of students agree with a statement about technology's benefits, but it offers limited insight into the diverse reasons for that agreement or the specific nuances of their understanding. Qualitative methods, including in-depth interviews and focus groups, excel at capturing the richness and depth of subjective experience. They allow participants to articulate their views in their own words, providing detailed narratives and uncovering underlying motivations. However, qualitative studies are typically labour-intensive and often involve smaller sample sizes, which can limit the generalisability of their findings to broader populations (Zabala et al., 2018). A mixed methods approach seeks to combine the strengths of both quantitative and qualitative paradigms, providing a more comprehensive understanding of phenomena. These designs can involve sequential or concurrent integration of data. While powerful, designing and executing effective mixed-methods studies requires careful consideration of how the different data types are integrated and interpreted to form a cohesive picture (Showunmi & Fox, 2018). Q methodology, as discussed subsequently, represents a unique mixed-methods approach that specifically addresses the challenge of systematically studying subjectivity (Desing & Kajfez, 2020; Rost, 2020; Zabala et al., 2018).

3. Q METHODOLOGY

3.1 Theoretical Underpinnings of Q Methodology

Q methodology, developed by William Stephenson in the 1930s, offers a systematic approach for investigating human subjectivity (Rost, 2020). It is a pragmatic, mixed-methods technique designed to identify and describe shared viewpoints or typologies of perspectives within a group

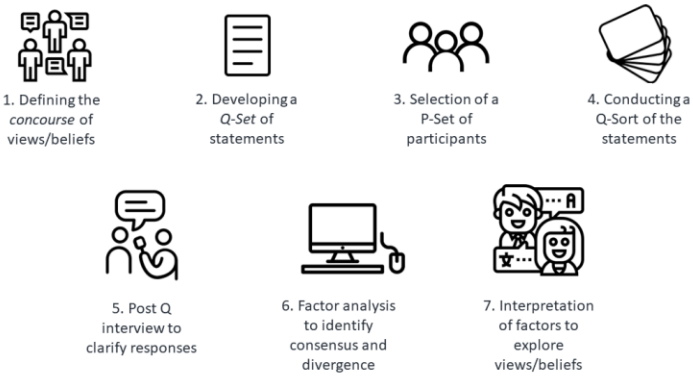
(Desing & Kajfez, 2020). Unlike conventional R-methodology, which correlates variables across a large sample of individuals, Q methodology correlates individual participants (or P-sets) across a large sample of variables (or Q-Set statements) (Rost, 2020). This inversion allows for the identification of distinct patterns of thought or subjective positions, rather than merely measuring traits (Zabala et al., 2018). The theoretical foundation of Q methodology rests on the principle that subjective experiences, while individual, often cluster into shared perspectives. Individuals who sort a set of statements similarly are understood to hold a common viewpoint on the topic under. The methodology explicitly embraces and quantifies subjectivity, making it a powerful tool for exploring complex human opinions, attitudes, and beliefs. Q methodology's distinctiveness arises from several features. Firstly, it focuses on the 'operant subjectivity' of participants, meaning it examines how individuals actively structure their understanding of a particular topic. This is achieved through the Q-sort, where participants rank-order a set of statements based on their agreement or disagreement, thereby revealing their unique perspective (Zabala et al., 2018). Secondly, Q methodology integrates both qualitative and quantitative techniques. The initial development of statements and the post-sort interviews provide rich qualitative data, while the factor analysis of Q-sorts offers a quantitative means to identify patterns and typologies (Desing & Kajfez, 2020). This convergent mixed-methods design explains quantitative results with qualitative findings, offering a comprehensive understanding.

3.2 The Advantages of Using Q Methodology

Philosophically, Q methodology aligns with a pragmatic tradition, emphasising the practical utility of understanding diverse viewpoints for addressing real-world problems. It acknowledges that multiple valid perspectives can exist on an issue, moving beyond a search for a single objective truth (Nilsson, 2018). This makes it particularly suitable for fields like TED education, where different stakeholders (students, teachers, policymakers) may hold varied, yet equally valid, understandings of curriculum, pedagogy, and educational goals (Willmott, 2020). Unlike similar approaches, such as Delphi method which aims to reach a consensus on a particular matter, Q methodology reveals different consensuses and distinguishing characteristics. Thus, is ideally suited to complex social and societal issues where there are different views, recognising and including views that might be obscured or excluded using consensus driven approaches.

4. APPLYING Q METHODOLOGY

FIGURE 1. *The seven stages of Q Methodology Research, © Matt McLain 2025*



4.1 The Seven-Stage Q Method Process in Practice

Q methodology involves a systematic, seven-stage process for investigating subjective viewpoints (Figure 1). This structured approach ensures rigour and facilitates the identification of distinct perspectives (Watts & Stenner, 2012). Deignan (2016) provides a useful 5-minute animation of the Q methodology procedure.

4.1.1 Stage 1: Constructing the Concourse

The initial stage involves defining the 'concourse,' which represents the full range of potential views and beliefs surrounding a specific topic. For TED education, this might involve collecting statements about curriculum relevance, teaching methods, technology integration, or student engagement. Sources for concourse statements can include academic literature, interviews with experts and practitioners, focus group discussions, media reports, and policy documents. The goal is to capture the breadth of opinion, not necessarily to endorse any particular view.

4.1.2 Stage 2: Developing the Q-Set

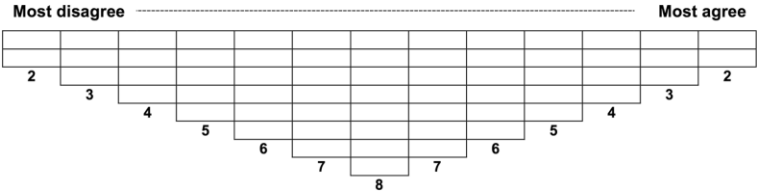
From the extensive concourse, a smaller, manageable set of statements, known as the 'Q-set,' is developed. This Q-set typically consists of 30 to 60 statements, each representing a distinct facet of the topic. The selection process ensures that the Q-set is representative of the concourse's diversity, balancing controversial, consensual, and neutral statements. Each statement is typically printed on a separate card for ease of manipulation by participants.

4.1.3 Stage 3: Selecting the P-Set

The 'P-set' refers to the sample of participants who will perform the Q-sort. Unlike traditional survey research, Q methodology employs a relatively small, purposive sample, usually between 20 and 60 individuals. The selection criterion is not statistical representativeness of a population, but rather a representation of diverse viewpoints relevant to the research question (Vecchio et al.,

2020). For example, a P-set in TED education research might include students, teachers, curriculum developers, and industry professionals. When selecting a P-Set, the researcher should consider the research aims and questions when identifying suitable participants. Q methodology comes into its own where there are contrasting and conflicting views. So, the P-Set should ideally include participants representing a diversity of views, beliefs and experiences, within the defined population (i.e. the aforementioned students, teachers, etc.).

FIGURE 2. *Example forced quasi-normal distribution grid (McLain, 2021)*



4.1.4 Stage 4: Conducting the Q-Sort

Participants perform the 'Q-sort' by arranging the Q-set statements onto a forced-choice distribution grid (McLain, 2021; Figure 2). This grid typically ranges from "most agree" to "most disagree" (e.g., +5 to -5), with a quasi-normal or normal distribution dictating how many statements can be placed at each point on the continuum. This forced distribution compels participants to make comparative judgments, revealing their subjective preferences and priorities. Each completed Q-sort constitutes a unique expression of a participant's viewpoint.

4.1.5 Stage 5: Post-Sort Interviews for Interpretative Depth

Following the Q-sort, participants are typically interviewed. These post-sort interviews serve to clarify the reasoning behind their sorting decisions, particularly for statements placed at the extremes of the continuum. This qualitative data provides crucial contextual information, explaining the subjective meaning participants attribute to the statements and enriching the subsequent interpretation of factors. The interviews also offer an opportunity for participants to elaborate on any statements they found ambiguous or particularly salient.

4.1.6 Stage 6: Factor Analysis of Q-Sorts

The completed Q-sorts are subjected to 'by-person factor analysis'. This statistical technique identifies groups of participants who have sorted the statements in a similar way, indicating shared viewpoints or 'factors' (Figures 3 & 4). Each factor represents a distinct subjective perspective on the topic. The analysis typically involves principal component analysis followed by a Varimax rotation to achieve orthogonal (uncorrelated). Standard software packages like PQMethod (Schmolck, 2014), an open access DOS-based programme which operates on Windows and has become the de facto analysis tool for Q methodology, are commonly used for this stage. For researchers using operating systems (OS) other than Windows, DOS emulators are freely

available, and the PQMethod website includes guidance for Mac and Linux users. However, there are other options that include a cloud-based package Ken-Q Analysis (Banasick, 2023), which also has a multiple OS desktop version called KADE (Banasick, 2019).

FIGURE 3. *Factor loadings with an × indicating a defining sort (McLain, 2021)*

Participant	Factor loadings			
	1		2	
1	0.5929	×	−0.4489	
2	0.6944	×	−0.2660	
3	−0.0252		−0.6533	×
4	0.7064	×	−0.4087	
5	0.1170		−0.4829	×
6	0.0636		−0.2836	
7	0.6701	×	0.2297	
8	−0.1445		−0.5187	×
9	−0.0025		−0.7156	×
10	−0.5678	×	0.0332	
11	0.6772	×	−0.2043	
% expl. var.	24		19	

FIGURE 4. *Excerpt of Factor Array and Ranking Table (McLain, 2021)*

Statement		Factor 1		Factor 2	
		Q-SV	Z-SCR	Q-SV	Z-SCR
*17	The teacher identifies the main points/steps for the learners	5	1.83	5	1.42
*1	The teacher gives an overview of the content of the skills or knowledge being demonstrated	4	1.45	4	1.31
*35	The teacher identifies hazards and risks for the learners	4	1.12	3	0.77
*60	The teacher makes his/her expectations of the learners'	3	1.03	2	0.54

4.1.7 Stage 7: Interpreting Factors and Generating Typologies

The final stage involves interpreting the identified factors and generating typologies of viewpoint. For each factor, a 'factor array' is constructed, representing the ideal sort for that particular viewpoint. Researchers then analyse the statements that define each factor, paying close attention to those ranked at the extremes and those that distinguish one factor from others. The qualitative data from the post-sort interviews are integrated at this stage to provide a rich, narrative description of each viewpoint. The outcome is a set of distinct, interpretable perspectives that collectively represent the diversity of opinion within the P-set.

4.2 Critical Considerations in Study Design and Implementation

4.2.1 Sampling Strategies and Statement Selection

While the P-set in Q methodology is small and purposive, its selection is not arbitrary. Researchers aim for a diverse P-set that encompasses individuals representing different known or hypothesised perspectives on the topic (Zabala et al., 2018). The goal is to capture the full range of subjective variability, not to be statistically representative of a larger population in the traditional sense. For instance, in TED education, this might involve recruiting students from different year groups, teachers with varying levels of experience, or professionals from diverse

engineering disciplines. Statement selection for the Q-set is equally critical. The statements must collectively cover the breadth of the concourse, avoiding redundancy while ensuring clarity and conciseness. Poorly constructed or ambiguous statements can compromise the validity of the Q-sorts. Pilot testing the Q-set with a small group of individuals can help refine statements and ensure they are understood as intended (Zabala et al., 2018).

4.2.2 Ensuring Trustworthiness and Rigor

Trustworthiness in Q methodology is established through a combination of systematic procedures and transparent reporting. The careful construction of the concourse and Q-set, coupled with the structured Q-sort process, contributes to the methodological rigour (Zabala et al., 2018). The inclusion of post-sort interviews provides a qualitative layer that enhances the interpretative depth and validates the quantitative findings. Researchers should meticulously document all stages of the process, from concourse development to factor interpretation. Clear reporting of the rationale for factor extraction (e.g., number of factors, rotation method) and detailed descriptions of each factor array are also essential for demonstrating rigour (Zabala & Pascual, 2016). Trustworthiness is further enhanced when the identified factors are internally consistent and align logically with the qualitative data gathered during interviews.

4.3 Comparison with Alternative Approaches to Investigating Subjectivity

4.3.1 Advantages of Q Methodology over Survey and Interview Methods

Q methodology offers several advantages when compared to traditional survey or interview methods for investigating subjectivity. Unlike surveys, which often constrain responses to predefined scales and may force participants into categories that do not fully capture their views, Q methodology allows participants to express their subjective understanding holistically through the ranking process (Rost, 2020). The forced-choice distribution in the Q-sort compels participants to prioritise statements, revealing their internal frame of reference rather than merely endorsing or rejecting isolated items.

Furthermore, while qualitative interviews provide rich data, their analysis can be highly interpretative and challenging to systematise across a group of individuals (Zabala et al., 2018). Q methodology overcomes this by combining the qualitative depth of individual sorting and post-sort interviews with the systematic identification of shared patterns through factor analysis. This integration provides a statistically derived, yet qualitatively interpretable, typology of viewpoints (Desing & Kajfez, 2020). It uniquely bridges the gap between individual qualitative expression and broader patterns of subjective understanding (Rost, 2020). The output of a Q study is a set of distinct 'factors' or groups of participants with broadly similar rankings. This generates a plurality of views rather than a single consensus view, making it particularly useful for understanding complex, contested issues in TED education where diverse perspectives are common.

4.3.2 Limitations and Potential Pitfalls

Despite its strengths, Q methodology is not without limitations. The construction of the concourse and Q-set requires careful attention to ensure comprehensive coverage of the topic, and any bias in statement selection can affect the results (Zabala et al., 2018). The small P-set size means that findings are not generalisable in the statistical sense to a larger population but rather represent a typology of viewpoints present within the selected sample. Another potential pitfall lies in the interpretation of factors. While statistical methods identify the factors, the naming and narrative description of each factor heavily rely on the researcher's qualitative interpretation of the defining statements and interview data (Nilsson, 2018). This requires a deep understanding of the research context and a commitment to avoid imposing pre-conceived notions. The methodology also demands a certain level of statistical literacy for appropriate factor analysis and interpretation.

5. IMPLICATIONS FOR TED EDUCATION RESEARCH

5.1 The Value of Plurality in Understanding Diverse Perspectives

Q methodology's capacity to uncover a plurality of subjective viewpoints represents a significant asset for TED education research. Educational contexts are inherently diverse, populated by individuals with varied backgrounds, learning styles, and motivations. Acknowledging and understanding this diversity is crucial for developing effective pedagogical strategies and curricula. Rather than seeking a single, universal perspective, Q methodology allows researchers to map out the different "ways of thinking" about an issue, providing a nuanced understanding of the landscape of opinions (Desing & Kajfez, 2020). For instance, a study could reveal distinct student perspectives on the value of hands-on projects versus theoretical instruction, offering educators specific insights into how different groups engage with learning activities.

5.1.1 Micro, Meso, and Macro-Level Applications

The insights gained from Q methodology can be applied across various levels within TED education. At the micro-level, understanding the subjective experiences of individual students or small groups can inform tailored instructional approaches or mentorship strategies. For example, identifying student typologies regarding their motivations for pursuing engineering can help instructors address specific needs and foster engagement (Desing & Kajfez, 2020). At the meso-level, Q methodology can reveal shared perspectives among faculty within a department, teachers across a school district, or industry partners collaborating with educational institutions. This can facilitate more effective communication and alignment of goals among stakeholders. For instance, uncovering different teacher perspectives on integrating new design software can guide professional development initiatives. At the macro-level, Q findings can illuminate diverse national or international perspectives on educational policy or curriculum reform, considering cultural nuances and differing priorities. This allows for the development of policies that are more sensitive to the varied contexts in which TED education operates globally.

5.2 Impact on Policy Development and Curriculum Design

By articulating distinct subjective viewpoints, Q methodology offers a robust evidence base for policy development and curriculum design in TED education. Policymakers often grapple with competing interests and diverse public opinions. Q findings can clarify the underlying perspectives driving these opinions, allowing for more targeted and acceptable policy interventions. For instance, understanding the varying perspectives of parents on TED education can inform public engagement campaigns or resource allocation decisions. In curriculum design, identifying student or teacher typologies concerning pedagogical approaches or content relevance can inform the creation of more adaptable and inclusive learning experiences. A curriculum responsive to diverse subjective positions is more likely to achieve its objectives and foster deeper engagement. For example, if distinct student groups hold different views on the importance of theoretical knowledge versus practical skills, curriculum designers can design learning that explicitly address these variations.

5.3 Enhancing Epistemological Foundations in TED through Robust Methodology

The application of Q methodology contributes to strengthening the epistemological foundations of TED education research. It provides a systematic, rigorous approach to understanding phenomena that are inherently subjective, moving beyond anecdotal evidence or broad generalisations. By integrating qualitative depth with quantitative analysis, it offers a verifiable method for discerning patterns of thought and belief, thereby adding a layer of scientific credibility to the study of subjective experiences (Desing & Kajfez, 2020). This method allows researchers to categorise and describe subjective views with clarity, making these often-intangible aspects of human experience amenable to scholarly inquiry. Such an approach fosters a more comprehensive and robust understanding of the complex interplay between individual perceptions and educational outcomes in TED fields. It enables the field to generate evidence-based insights into how beliefs shape practice and learning, moving beyond simplistic cause-and-effect models.

5.4 Challenges to Integration and Future Directions

Despite its utility, integrating Q methodology more broadly into TED education research faces challenges. These include a lack of widespread familiarity with the method among researchers in the field, as well as perceptions regarding its methodological complexity. Addressing these challenges necessitates increased training, methodological guidance, and exemplary case studies showcasing Q methodology's value within TED contexts (Desing & Kajfez, 2020). Future directions for Q methodology in TED education could involve longitudinal studies to observe how subjective views evolve over time, or comparative studies across different cultural contexts. Further methodological innovations, such as combining Q methodology with other qualitative methods like discourse analysis, could provide even richer insights into the formation and expression of subjective views (Hagan & Williams, 2016). Additionally, exploring the use of

digital tools for Q-sorting could streamline data collection and enhance accessibility for a broader range of participants.

6. CONCLUSION

6.1 Synthesising Insights on Q Methodology in TED Research

This primer has presented Q methodology as a robust and valuable approach for investigating subjective views and beliefs within TED education research. It has detailed the seven-stage process, from concourse development to factor interpretation, highlighting how this method systematically identifies distinct typologies of perspectives (Zabala et al., 2018). The unique integration of qualitative and quantitative techniques in Q methodology allows for a deep, nuanced understanding of human subjectivity, moving beyond the limitations of traditional survey or interview methods (Desing & Kajfez, 2020; Rost, 2020). By revealing a plurality of viewpoints rather than a singular consensus, Q methodology accurately represents the complexity inherent in educational contexts. This capacity for uncovering diverse perspectives is particularly pertinent for TED education, a field characterised by its dynamic nature and varied stakeholder experiences across micro, meso, and macro levels.

6.2 Recommendations for Researchers and Practitioners

For researchers in TED education, incorporating Q methodology into their methodological repertoire can yield significant benefits. It offers a powerful tool for exploring complex issues such as student motivation, teacher perceptions of new technologies, or industry perspectives on curriculum relevance. TED education researchers should: (i) thoroughly **develop the concourse**, ensuring the Q-set statements comprehensively capture the diversity of opinions on the topic; (ii) **select a purposive P-set**, choosing participants who represent the range of relevant viewpoints, not just a statistically large sample; (iii) **integrate post-sort interviews**, using qualitative data to enrich the interpretation of factors and provide context for the statistical findings; and (iv) **report transparently**, clearly articulating methodological decisions and the interpretation process to enhance trustworthiness. For practitioners and policymakers, the typologies of views identified through Q methodology can inform more responsive policy development and curriculum design. Understanding the distinct subjective positions held by different groups allows for the creation of targeted interventions and more effective communication strategies that resonate with specific audiences.

6.3 Future Pathways for Methodological Innovation in TED Education

Future research could explore the application of Q methodology in longitudinal studies to track shifts in subjective views over time, particularly in response to educational reforms or technological advancements. Comparative studies using Q methodology across diverse cultural

and educational systems could also yield valuable cross-cultural insights into TED education. Combining Q methodology with other research paradigms, such as critical theory or design-based research, could provide even deeper analytical perspectives on subjective experiences in educational transformation. Continuous exploration of methodological innovations will strengthen the academic rigour and practical relevance of TED education research.

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Maker Spaces as Learning Environments: An Empirical Study on Educational Goals and Methods

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Abstract

Maker Spaces and the Maker Education that takes place within them represent a largely non-institutionalized form of technology education. In addition to fostering 21st Century Skills, they are often associated with the development of specific abilities such as technical skills and computational thinking. Unlike formal educational institutions, learning in Maker Spaces frequently occurs through hands-on, technology-driven, and open-ended activities. In an exploratory empirical study, 147 Maker Spaces in Germany were analyzed, with particular attention to those offering programs for children and adolescents. Using standardized questionnaires, the study examined which goals—framed within an extended 4C framework that includes technical skills and computational thinking—and which teaching methods are emphasized in these spaces. The results show that Maker Spaces primarily aim to foster technical skills and creativity, while computational thinking and social-oriented skills such as collaboration and communication play a comparatively smaller yet still notable role. To achieve these goals, open-ended methods such as open making and project-based learning are used most frequently, while more structured approaches like Design Thinking and Challenges are less common. Additionally, the study found that gender-specific programs are more commonly available for girls than for boys. Given that many Maker Spaces operate independently of formal curricula, the findings provide insights into their educational priorities and practices, allowing for comparison with theoretical models of Maker Education. Moreover, the results contribute to ongoing research on the specific learning potential of methods used in these open educational environments.

Key Words: Maker Spaces, Maker Education, 21st Century Skills, Technology Education, STEAM learning

1. INTRODUCATION

In recent years, the global educational landscape has undergone significant changes. There is a growing shift toward practice-oriented and student-centered forms of learning (González-Pérez & Ramírez-Montoya, 2022). Traditional teaching approaches, which primarily focus on theoretical knowledge transfer and teacher-centered instruction, are increasingly being replaced by more methodologically diverse and skills-oriented formats that foster independent thinking,

experimentation, and problem-solving (Robinson & Aronica, 2016; Robinson, 2012). Against the backdrop of a digitized and technologized society, the so-called 21st Century Skills are gaining particular relevance. These include creativity, critical thinking, communication, and collaboration, often grouped under the acronym "4C" (in German: „4K“). These skills are considered essential for social participation and professional success and are now embedded in numerous curricula and reform initiatives—among others within the framework of the OECD project “Future of Education and Skills 2030” (OECD, 2018).

In the context of technology education, Maker Spaces and Maker Education are increasingly coming into focus as innovative learning environments. Due to their open, technology-supported, and hands-on nature, they offer a learning-conducive environment for the development of these skills. Iwata et al. (2020) identify Maker Spaces as learning environments that can particularly promote 21st Century Skills and Computational Thinking. A broader review of the research literature also points to the potential of Maker Spaces for such skill development—beyond that, also for fostering technical skills and problem-solving abilities (e.g., Freiman, 2020; Ioannou & Gravel, 2024; Rayna & Striukova, 2021).

Despite this potential, there are challenges in integrating Maker Education into formal educational processes. Iwata et al. (2025) report that maker educators often work without systematic reference to a comprehensive skills framework, instead orienting themselves to school curricula or personal experience. As a result, the potential of Maker Spaces to promote transversal skills is not yet being systematically utilized. Furthermore, Maker Education—like many educational innovations—relies on openness and flexibility, which can lead to friction with traditional educational structures (Nemorin & Selwyn, 2017). It is also important to note that many Maker Spaces are not directly affiliated with schools but rather function as informal learning spaces that are not bound to curricular frameworks and design their offerings independently. Which specific 21st Century Skills are promoted there, and which didactic methods are used to do so, has so far not been systematically captured. Therefore, a differentiated analysis of the actual learning environments in Maker Spaces is necessary in order to identify their potential and priorities and to make them purposefully usable for promoting future-relevant skills within the scope of technology education.

Against this background, the following central research question arises: Which 21st Century Skills—including Computational Thinking and technical Skills—are promoted in Maker Spaces for children and adolescents, and through which didactic methods are they fostered?

2. LITERATURE REVIEW

2.1 Maker Spaces and Maker Education

At the time of writing, there is no universally accepted definition of the term "Maker Space" (Van Holm, 2015). In the literature, Maker Spaces are often described as multifunctional spaces equipped with a wide range of tools and technologies, representing an intersection between traditional craftsmanship and digital fabrication technologies (Blikstein, 2013; Schön et al., 2014; Blackley et al., 2017; Alberghina, 2021). Typical equipment includes hand tools, 3D printers,

laser cutters, CNC milling machines, and microcontrollers such as Arduino or Raspberry Pi (Wiemer & Degen, 2025; Klapwijk et al., 2023). These workshops enable learners to implement technical-creative ideas and to learn through active "making"—that is, by independently trying things out and experimenting (Dougherty, 2012).

A central characteristic of Maker Spaces is their high degree of flexibility. They are not bound to fixed structures and can be designed differently depending on the target group and context. Rothe, Landherr, and Wiemer (2025) emphasize that Maker Spaces can range from high-tech workshops with digital fabrication tools to simple woodshops.

In educational contexts, the didactic foundation of Maker Spaces is often grounded in Maker Education, which builds on the constructivist learning theory of Seymour Papert. According to Papert, people learn most effectively through practical action and the realization of their own projects (Ackermann, 2001; Papert & Harel, 1991). Libow Martinez and Stager (2013) divide the educational making process into three ideal-typical, iterative phases: thinking (e.g., problem definition, planning), making (e.g., building, crafting, programming), and improving (e.g., discussion, material variation). Maker Education does not prescribe specific content or solutions but encourages learners to develop their own ideas, make mistakes, and learn from each other through exchange (Maurer & Ingold, 2023). Typical methodological approaches include project-based learning and open-ended tinkering (Schön et al., 2019).

2.2 21st century skills and the 4c

As stated in the introduction, one of the primary goals of Maker Spaces is to foster 21st Century Skills, in particular the 4C: creativity, critical thinking, collaboration, and communication, as well as technical skills and computational thinking (Binkley et al., 2012). These additional components, technical skills and computational thinking, require appropriate conceptual framing.

An analysis of established 21st century skills frameworks shows that information and communication technologies (ICT) play a central role in developing these key skills (Voogt & Roblin, 2010; Lewin & McNicol, 2015). The focus is not solely on the use of digital tools, but also on their critical, creative, and problem-solving application. Van Laar et al. (2017) demonstrate that digital skills are closely intertwined with the classic 4C skills while also adding a technological knowledge dimension essential for modern life and work environments (Deursen & Van Dijk, 2010; Iwata et al., 2020). Computational thinking helps learners structure problems in ways that make them solvable through algorithms—a core component of creative and analytical problem-solving (Rode et al., 2015).

Technical skills support the ability to understand the interplay between technology and society and to consider this interaction when addressing complex tasks (Yeşilyurt & Vezne, 2023). A conceptual basis for technical skills in educational contexts is provided by the Standards for Technological Literacy (STEL) from the International Technology and Engineering Educators Association (ITEEA). These standards define technical skills across educational levels as the integration of action-oriented, interdisciplinary skills (International Technology and Engineering Educators Association [ITEEA], 2020).

2.3 Extended 4C Framework for Research

Taken together, the skill dimensions outlined in the previous section, including the core 4C as well as the additional components, constitute what is referred to in this study as the extended 4C framework, which includes: creativity, critical thinking, collaboration, and communication, technical skills and computational thinking. This extension provides a more comprehensive foundation for the analysis that follows.

A final consideration for the research was the distinction between action-oriented skills and socially oriented skills within this extended 4C framework. This differentiation was made based on the assumption that institutions not affiliated with formal education providers and originally rooted in the maker movement may not clearly distinguish between different types of skills, which could result in unclear goals and reveal latent groupings. The concrete categorization follows the model proposed by Gessler and Sebe-Opfermann (2022): action-oriented skills include creativity, technical skills, and computational thinking. These primarily involve the ability to act independently and practically, solve problems, and develop new ideas. In contrast, social-oriented skills include collaboration, communication, and critical thinking and refer to the ability to work effectively with others, communicate, and develop solutions collaboratively.

3. METHODOLOGY

3.1 Procedure

To answer the research question, a total of 423 institutions within the spectrum of open workshops in Germany were invited to participate in an online survey. The data collection was carried out using a standardized questionnaire developed and distributed in spring 2025 at the University of Potsdam. Completing the questionnaire took approximately eight minutes. It included both closed Likert scales and matrix questions linking methods to skills, as well as multiple-choice formats. The sample included institutions that—regardless of their institutional affiliation—identify as Maker Spaces, FabLabs, open workshops, or comparable formats.

In total, 147 institutions completed at least part of the questionnaire, resulting in a response rate of approximately 34.8%. Around 62% of the responses indicated that they offer specific programs for schools and/or for children and adolescents. For analyses that focus exclusively on this subgroup, the relevant base population is indicated separately in the corresponding hypothesis testing.

According to current estimates, there are approximately 500 open workshops in Germany (Netzwerk Offener Werkstätten e. V., 2023). This study thus covers about 29% of the estimated population—a solid basis for exploratory empirical analysis (Akremi, 2014, p. 280), especially in light of the decentralized, heterogeneous, and dynamic structure of these institutions. The results are not intended to be statistically representative, but they can be interpreted as structurally typical for Maker Spaces that offer programs for children and adolescents.

3.2 Research Questions and Derived Hypotheses

Based on the theoretical considerations, several research questions and associated hypotheses were developed. The first question addresses self-assessed goals: Which of the extended 4C skills are considered objectives according to the self-assessments of the institutions? From this, two hypotheses were derived:

(i) Institutions that offer targeted programs for children or adolescents assess their goals differently than those without such programs.
(ii) Action-oriented skills (creativity, technical skills, computational thinking) are rated more highly than social-oriented skills (collaboration, communication, critical thinking).

The second question focuses on the actual promotion of skills and reads: Which of the extended 4C skills are being promoted in the participating institutions that offer educational programs for children and adolescents? The corresponding hypotheses are:

(iii) The educational programs predominantly promote action-oriented skills.
(iv) Technical skills are, on average, promoted the most.

The third question examines the methods used across institutions: Which methods are actually implemented in the institutions? Three hypotheses were derived:

(v) Open formats (e.g., open making, challenges) are used more frequently than structured ones.
(vi) Institutions with educational programs use different formats than those without.
(vii) The stronger an institution identifies as an educational provider, the less frequently it uses open making formats.

The fourth question addresses the perceived suitability of methods for skill promotion: According to the institutions offering programs for children and adolescents, which methods are considered particularly suitable for promoting specific skills? The following hypotheses were formulated:

(viii) Project-based learning is perceived as particularly broadly effective (i.e., linked to many different skills).
(ix) Creativity is primarily associated with open making.

3.3. Analysis Methods

The data were analyzed using SPSS 29 and Excel. The evaluation began with descriptive analyses to identify central tendencies and distributions (Baur & Blasius, 2014, p. 998). For inferential statistical testing of the hypotheses, non-parametric methods were primarily used, as most of the instruments employed endpoint-oriented Likert scales whose interpretation as metric data is not consistently justified.

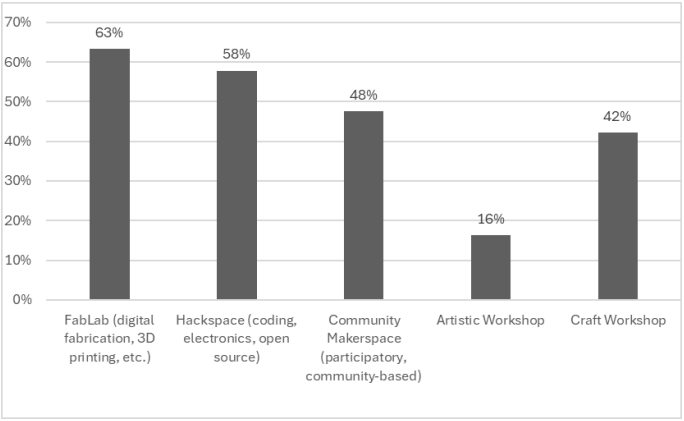
Specifically, hypotheses involving comparisons of ratings within the same institution—such as comparing action-oriented and social-oriented skills—were tested using the Wilcoxon signed-rank test for paired samples (Bortz & Schuster, 2010, p. 133). For group comparisons—e.g., between Maker Spaces with and without targeted programs for children and adolescents—the Mann–Whitney U test was applied, a suitable procedure for analyzing differences between two independent groups with ordinal data (University of Zurich, n.d., Mann–Whitney U Test). To evaluate rank-based assessments of multiple characteristics within an institution—such as which skills or methods are most frequently promoted—the Friedman test was used (University of Zurich, n.d., Friedman Test). When analyzing correlations between two individual ordinal variables, such as the self-identification as an educational provider and the use of open formats, the Spearman rank correlation was employed (Bortz & Schuster, 2010, p. 178). Structural differences in the frequency of associations between methods and skills were tested for significance using the Chi² test (Moosbrugger & Kelava, 2012, p. 307). Complex relationships—especially the assessments of the suitability of methods for different skills—were visualized using heatmaps to clearly present patterns and focal points in the response behavior (cf. Atlassian, 2025).

4. RESULTS

4.1 General Sample Data

As shown in Figure 1, the self-descriptions of the participating institutions (n = 147) vary; multiple responses were possible. Most institutions identify as a FabLab or Hackspace, while only a few (16%) also see themselves as artistic workshops.

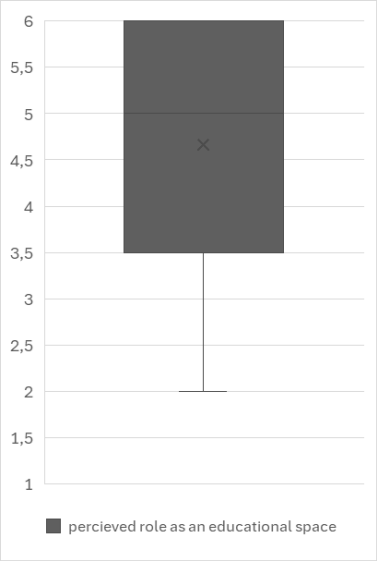
Figure 1.
Self-description of participating institutions (percentage of surveyed Maker Spaces)



34% of the surveyed institutions are directly affiliated with an educational institution. The distribution is as follows: 9% are connected to a school, 14% to a university, 3% to an adult

education center, and 14% to another type of educational institution. Regardless of institutional affiliation, the statement “My Maker Space is an educational provider” was rated on a six-point Likert scale from “strongly disagree” to “strongly agree” with an average of 5.2 (n = 118). This indicates that the institutions predominantly view themselves as educational spaces (see Figure 2).

Figure 2.
Boxplot of the participating institutions' self-assessment as educational providers

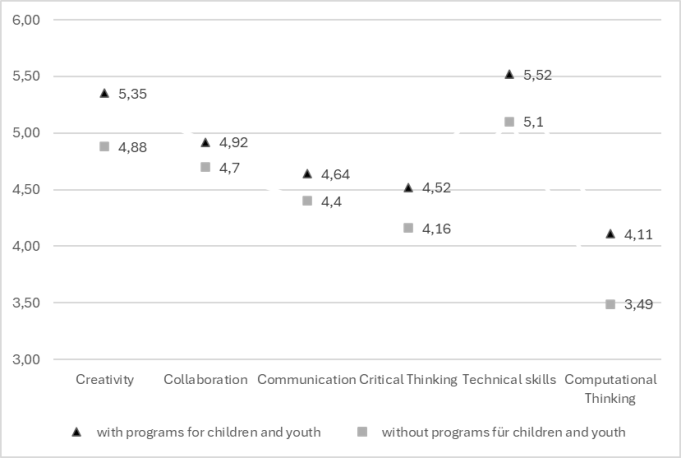


Of the institutions that responded to this question (n = 112), 55% indicated that they offer specific programs for children and adolescents, 88% for adults, and 37% also provide targeted programs for schools. Additionally, 16% of respondents (n = 128) stated that they offer specific programs for girls, and 4% for boys.

4.2 Self-assessed goals within the extended 4C skills

The first research question addresses the fundamental issue of which skills from the extended 4C framework are considered goals in the institutions’ self-assessments (survey item: “Which goals do you associate with your institution?”; six-point endpoint-oriented Likert scale from “not important” to “very important”; n = 118), and whether differences exist between institutions with educational programs for children and adolescents and those without such programs. Overall (see Figure 3), institutions that offer programs for children and adolescents rate all target skills more highly than those without such programs.

Figure 3.
Mean values of the target skills reported by institutions with and without programs for children and adolescents



The first step analyzes whether institutions with targeted programs for children and adolescents prioritize their goals differently than those without (Hypothesis i). Mann–Whitney U tests show that institutions offering programs for children and adolescents place significantly greater emphasis on technical skills ($U = 1195.00$, $p = .021$). For creativity ($p = .071$) and computational thinking ($p = .053$), the differences are not statistically significant but indicate noticeable trends. These suggest that these goals have systematically higher importance in educationally active institutions, even though the differences do not meet the conventional significance threshold of $p < .05$. The lack of significance is likely due to greater variability and overlap in the ratings between the groups, which can reduce test power in non-parametric procedures like the Mann–Whitney U test.

To evaluate which target skills are prioritized by the institutions (Hypothesis ii), the ratings of the six skills were grouped and compared. Specifically, the analysis assessed whether action-oriented skills (creativity, technical skills, computational thinking) are rated more highly than social-oriented skills (collaboration, communication, critical thinking). A Wilcoxon signed-rank test revealed a significant difference, $Z = –2.267$, $p = .023$, in favor of the action-oriented skills.

4.3 Promotion of Skills in Educational Programs

After examining the target perspective, the next step is to analyze which of the extended 4C skills are considered to be most strongly promoted in Maker Spaces that offer programs for children and adolescents, according to the respondents (survey item: “If you offer programs for children and adolescents, to what extent do these support the development of the following skills, in your opinion?”; six-point endpoint-oriented Likert scale from “not at all” to “very strongly”; $n = 62$). The mean values indicate that technical skills and creativity play a central role (see Table 1).

Table 1.
Mean values of skill promotion in institutions with programs for children and adolescents

Creativity	Collabo-ration	Communi-cation	Critical Thinking	Technical skills	Computat-ional Thinking
4,79	4,31	4,23	3,94	5,16	3,98

To test Hypothesis iii, which states that action-oriented skills (creativity, technical skills, computational thinking) are more strongly promoted than social-oriented skills (collaboration, communication, critical thinking), a Wilcoxon signed-rank test for paired samples was conducted. This test revealed a significant difference, $Z = –4.398$, $p < .001$, in favor of the action-oriented skills—confirming the tendency already observed in the goal assessment.

To test Hypothesis iv, whether technical skills are promoted more than any other skill, a Friedman test was conducted. This test also yielded a significant result, $\chi^2(5) = 80.359$, $p < .001$. The analysis of mean ranks (Table 2) shows that technical skills (4.69) rank highest, followed by creativity (4.27). Computational thinking, with a mean rank of 2.94, is rated much lower—at a similar level as critical thinking (2.71).

Table 2.
Mean ranks of skill promotion, Friedman test (1 = least mentioned, … most mentioned)

Art	Creativity	Collabo-ration	Communi-cation	Critical Thinking	Technical skills	Computat-ional Thinking
Mean rank	4,27	3,27	3,12	2,71	4,69	2,94

4.4 Method Use

The next step analyzes the methods used in the participating institutions (survey item: "How frequently do you integrate the following methods and approaches into your programs?"; six-point endpoint-oriented Likert scale from "never" to "very frequently"; n = 87). Figure 4 displays the mean values for all participating institutions, broken down by whether or not they offer programs for children and adolescents.

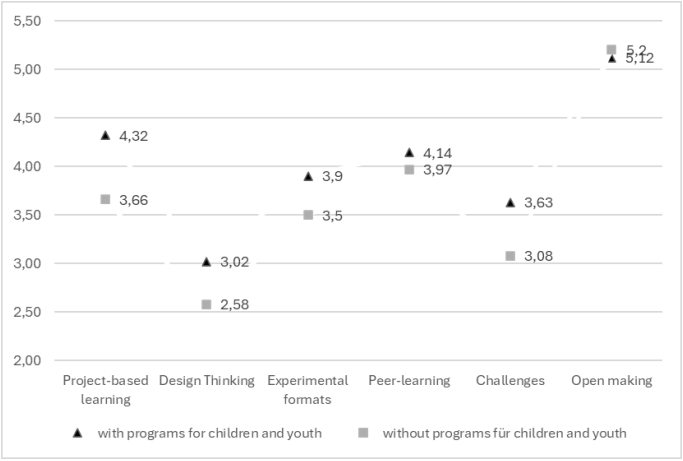
To analyze overall methodological practice, mean ranks were calculated using a Friedman test to identify differences in the frequency of use across formats. The test yielded a significant result, $\chi^2(5) = 92.028$, $p < .001$. The most frequently used method is open making (mean rank = 4.83), followed by project-based learning (3.74), peer learning (3.49), and experimental formats (3.40). Design Thinking (2.45) is used considerably less often. These results confirm Hypothesis v, which states that open formats tend to be used more frequently than structured ones (see Figure 4).

Table 3.
Mean ranks of method frequency, Friedman test (1 = least use, … highest use)

Art	Project-based learning	Design Thinking	Experi-mental formats	Peer-learning	Challenges	Open making
Mean rank	3,74	2,45	3,40	3,49	3,09	4,83

In a further step, Mann–Whitney U tests were used to determine whether institutions with educational programs use different methods than those without such programs. For none of the examined methods—including project-based learning ($U = 731.5$, $p = .060$) or challenges ($U = 705.0$, $p = .144$)—was a statistically significant difference found. All differences remained below the conventional significance threshold of $p < .05$, leading to the rejection of Hypothesis vi. The lack of significance despite differences in means likely reflects rank overlaps and variation within the groups.

Figure 4.
Mean values for method use in institutions with and without programs for children and adolescents



Lastly, the relationship between the institutions' self-identification as educational providers and their use of open making was examined. A Spearman rank correlation revealed a non-significant relationship, $r_s = .028$, $p = .793$. Therefore, Hypothesis vii, which posits that a stronger educational self-conception corresponds to less use of open formats, is not supported.

4.5 Perceived Method Effectiveness

In line with the final research question—"According to the institutions offering programs for children and adolescents, which methods are considered particularly suitable for promoting specific skills?"—the mean values were first visualized using a heatmap (see Figure 5) (survey

item: “In your opinion, which methods are particularly suitable for achieving each of the following goals?”; matrix question, n = 109). The results show expected associations, such as project-based learning being strongly linked to collaboration and communication, and creativity being most frequently associated with open making.

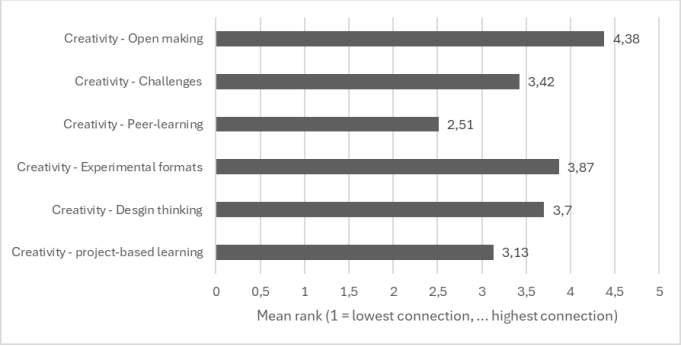
Figure 5.
Heatmap: Methods and extended 4C skills

	Creativity	Collaboration	Communication	Critical Thinking	Technical Skills	Computational Thinking
Project-based learning	30	65	66	33	38	19
Design Thinking	47	28	35	55	26	12
Experimental formats	49	31	29	48	52	20
Peer-learning	13	57	61	18	32	15
Challenges	38	42	39	46	48	29
Open making	63	30	35	62	65	33

To test Hypothesis viii, which posits that project-based learning is perceived as particularly broadly effective (i.e., linked to a wide variety of different skills), a Friedman test was conducted to assess the number of skill associations per method. The test yielded a significant result, $\chi^2(5) = 38.294$, $p < .001$. However, the highest mean ranks were observed for open making (4.46) and challenges (3.82), while project-based learning (3.50) ranked in the middle. Therefore, the hypothesis cannot be confirmed.

Finally, the hypothesis that creativity is most frequently associated with open making (Hypothesis ix) was examined. Another Friedman test analyzing the associations of creativity across all methods produced a highly significant result, $\chi^2(5) = 62.267$, $p < .001$ (see Figure 6). The highest mean rank was attributed to open making (4.38), followed by experimental formats (3.87) and Design Thinking (3.70). Thus, the hypothesis is clearly supported: among respondents, open making is considered the method most strongly associated with the promotion of creativity.

Figure 6.
Mean ranks of creativity associations, Friedman test



5. DISCUSSION

The findings of this study clearly show that the examined institutions within the Maker Space spectrum—with or without specific educational programs for children and adolescents—primarily identify action-oriented components of the extended 4C skills as their main goals, particularly technical skills and creativity. These priorities are not only reflected in the self-assessments but, in the case of institutions offering programs for children and adolescents, also in the evaluations of the actual skills promoted through their offerings. Whether these assessments align with the actual learning outcomes remains a question for future research.

The relatively low emphasis on computational thinking among the surveyed institutions with educational programs—both as a target and as a promoted skill—suggests that Maker Spaces focus less on core competencies of computer science education and more on a broader understanding of technology that corresponds more closely to the goals of technology education. This is a relevant finding for understanding the positioning and potential of these learning environments.

In terms of methodology, institutions—regardless of whether they offer educational programs—tend to prefer open formats such as open making or peer learning. No significant differences were found between groups in this respect. However, the association between creativity and open making was clearly demonstrated and corresponds with the educational principles of Maker Education. Interestingly, project-based learning was not perceived as particularly broadly effective, which contrasts with its common status in formal educational settings.

Overall, the results illustrate the potential of Maker Spaces for contributing to technology education. This is particularly evident in the prioritization of technical skills and (technological) creativity. Looking forward, it will be essential to investigate more precisely how the promotion of technical skills takes place in open learning environments, how these processes can be supported, and how they can be didactically operationalized in ways that meaningfully complement formal technology education.

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Factors contributing to the prevalence of Cyberbullying against students with disabilities and their implications for educational technologies design: A case in high learning institutions in South Africa

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Abstract

This study investigated the factors predicting the prevalence of cyberbullying on students with disabilities in South African higher learning institutions and their implications for educational technologies design. Although use of technology is encouraged among the youth to enable learning and social relationships in schools, there is growing misuse through cyberbullying of the disables. Understanding the challenges faced by these learners is critical to the design of appropriate educational technologies and to the creation of an inclusive learning environment. Limited research focuses on cyberbullying of the disabled in higher institutions and the impact influencing factors can have on the design and use of educational technologies and prevention of undesirable behaviour. The study adopted the Theory of Planned Behaviour (TPB) and the Spiral of Science to examine the factors predicting cyberbullying prevalence of the disabled and the design considerations for educational technologies.

A quantitative analysis of survey responses from students revealed that Subjective Norms predicted cyberbullying prevalence the most, followed by Perceived Social consequences. Attitude towards cyberbullying was not found to be significant by disabled respondents. We also found that prevalence of cyberbullying did not differ by Age and Gender of the disabled. The findings highlight important design considerations for educational technologies for the disabled. They imply that design strategies should aim to integrate awareness creation of cyberbullying, effective reporting mechanisms, inclusive digital literacy programs and safer digital learning environment. This would prevent actions leading to abuse of students with disabilities and promote inclusive learning. It also implies that educators have the responsibility to assist disabled students learn how to identify and respond to cyberbullying

Cyberbullying of disabled students, Higher learning institutions, Predictors, Prevalence, South Africa, Implications for educational technologies design

1. INTRODUCTION AND PROBLEM STATEMENT

While students with disabilities are typically thought to be more susceptible to experiencing both offline and online bullying, very few studies have focused on the emotional and behavioural reasons for cyberbullying students with disabilities in South Africa (Cilliers, 2021) and the prevalence of such aggression on disabled university students who usually face unique challenges when operating online has not been studied extensively (Touloupis, 2022). While there has been incorporation of this issue into university policy and curriculum by some institutions in South Africa, this is more recent (Cilliers, 2021; Ganca & Kyobe, 2023) and the implementation is usually slow. Understanding the prevalence of this social issue is essential for creating effective interventions and policies tailored to the specific needs of these victims. The term "prevalence" in this study refer to the frequency and magnitude of cyberbullying episodes within a certain population or online community. As higher learning institutions increasingly integrate mobile and digital platforms into teaching, cyberbullying poses a challenge not only to student wellbeing but also to the design and delivery of inclusive digital education. The effects of cyberbullying include depression, anxiety, and withdrawal which undermine the educational outcomes technology is meant to enhance. By understanding its prevalence, institutions can better design digital platforms and curricula that integrate protective features, responsible-use education, and interventions that mitigate risks. This positions the issue squarely within the scope of technology education and design.

The primary research question for this study is:

What are the factors predicting the prevalence of cyberbullying against students with disabilities in higher learning institutions?

The main objective of this study is to determine the specific factors that predict the prevalence of cyberbullying against students with disabilities in higher learning institutions. It also seeks to identify the implications for the design of educational technologies.

2. LITERATURE REVIEW

2.1. Traditional Bullying, Cyberbullying and Mobile Bullying

Bullying is a type of aggressive conduct that usually consists of repeated episodes including an imbalance of power between the target and the perpetrator(s). Bullying can take many different forms; these include relational or indirect bullying, cyberbullying, physical bullying, and verbal bullying (Olweus et al., 2019). Traditional bullying is a form of bullying that entails repeatedly inflicting harm purposefully and frequently on people over time. Bullies and victims must be present for it to occur. Generally, this violent behaviour is used as a form of control over peers and to establish a form of hierarchy in a friend group. The victims, who are typically weaker, succumb to the bullying perpetrators because of this conduct. Bullies hurt others by kicking or making fun of them verbally or physically (Aikins & Kyobe, 2021). Cyberbullying is characterized by a group or an individual's intentional and persistent aggression through the use of electronic communication means. Direct or indirect cyberbullying is possible (Cilliers, 2021). Direct cyberbullying is when a cyberbully and their victims communicate with each other directly. When someone engages in indirect cyberbullying, they don't speak with their victims

directly. Nevertheless, the target is met with unfavourable content via digital communication platforms including the internet and mobile devices (Shaikh et al., 2021). Mobile bullying, a subset of cyberbullying, has emerged through the pervasive use of mobile devices (Aikins & Kyobe, 2021).

Mobile bullying, like cyberbullying, includes behaviours such as cyberstalking, outing, trickery, denigration, flaming, harassment, and impersonation. For example, flaming involves hostile personal attacks in online platforms, while harassment includes threats or humiliation through mobile devices. Denigration involves posting derogatory comments about someone online. Overall, mobile bullying uses mobile technology to harm or undermine individuals (Eldridge et al., 2021).

2.2. Cyberbullying of students with disabilities

Disability is the state of having less ability to operate because of an illness, accident, disease, or other health problem, which results in limitations on one's activities or ability to participate in some aspects of one's surroundings (Ferguson & Nusbaum, 2012). Disability-related traits may be linked to a higher chance of cyberbullying and cyber victimisation. For instance, compared to students without disabilities, students with difficulties with learning are more likely to engage in cyberbullying and become victims of it (Eldridge et al., 2021). Students with disabilities frequently experience difficulties establishing and sustaining relationships with peers and adults, are less accepted by their peers, and are more likely to experience depression, anxiety, and loneliness. Given their poorer self-esteem and self-concept, they require additional support from friends, family, instructors, and coworkers. Along with low self-esteem and poor social skills, these students also report emotional and social challenges. Given their frequent and unsupervised use of social media, students in higher education with disabilities are therefore regarded as a vulnerable category and are more likely to become victims of mobile bullying (Souza et al., 2018).

Studies show that students with disabilities experience higher rates of peer victimization than the general population. This increased risk may be due to their noticeable differences, such as physical impairments or sensory loss, though the exact reasons remain unclear (Lund & Ross, 2021). Almost all teenagers, including those with disabilities, use the internet and digital technology, with many constantly online. Frequent computer use increases their risk of cyberbullying, and teens with disabilities are more likely to form close online relationships and share personal information, making them more vulnerable. They also experience cyberbullying as bystanders, highlighting the need to focus research on their online experiences (Wright & Wachs, 2020).

3. THEORETICAL BACKGROUND

3.1. Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) posits that human actions are predicated upon systematic and deliberate cognitive processes. Central to this theory are three constructs: attitudes, subjective norms (SN), and perceived behavioural control (PBC). Within the framework of TPB, an individual's intention to undertake a specific action is influenced not only by their attitudinal

disposition towards the behaviour but also by the prevailing subjective norms and their perceived behavioural control (Santre, 2021).

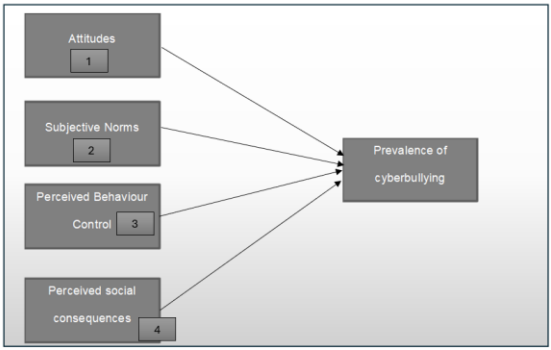
3.2. The Spiral of Silence Theory

One of the most interesting theories about public opinion and its function in society is the spiral of silence idea. It was created by German sociologist and political scientist Elizabeth Noelle-Neumann in the 1970s. The theory is predicated on the irrational approach to public opinion, which is said to exert control over the population and maintain the integrity of society by defining what is moral or immoral, good, or terrible, and right or wrong (Hakobyan, 2020).

The Theory of Planned Behaviour and the concept of the Spiral of Silence together offer a good basis for examining cyberbullying conduct against the disabled. According to the Theory of Planned behaviour (TPB), people's intentions to engage in certain conduct are influenced by their attitudes, subjective norms, and perceived behavioural control. On the other side, the Spiral of Silence theory postulates that people are more likely to keep quiet about a certain subject if they think their beliefs are in the minority and won't be accepted by the majority. By combining the Spiral of Silence and the Theory of Planned Behaviour frameworks, the researcher can examine the interplay between socio-cultural influences and individual decision-making processes (Hakobyan, 2020; Santre, 2021). For technology education and design, these theories provide a framework for embedding preventive features into digital platforms and for guiding the development of educational programs that address social pressure and behavioural control in online context.

3.3. Proposed Conceptual Model

Figure 1: Conceptual Model – Predictors of the prevalence of cyberbullying on the disabled. (Adapted from (Shawal et al., 2017)



3.3.1. Description of the conceptual model, constructs and hypotheses

Prevalence of Cyberbullying

The term "prevalence" in this study refers to the frequency and magnitude of cyberbullying episodes within a certain population or online community. The increased availability and use of the Internet yields benefits like easy access to education, medical, online banking, online shopping, etc. However, it also contributes to cyberbullying (Barlett et al., 2021; Tiffany, 2018). Estimating precise prevalence rates of cyberbullying perpetration and victimization is challenging due to the ongoing variances in operational definitions and methods of measurement. It is important to understand the factors predicting this aggression especially against the most vulnerable if appropriate interventions and preventions are to be achieved (Gaffney et al., 2019).

Attitudes towards Cyberbullying

Cyberbullying is caused by a variety of variables, such as psychological and personal aspects. Individual differences in personal characteristics, which have an impact on cyberbullying attitudes, exist. The two key personal elements linked to cyberbullying behaviour are awareness of cyberbullying and personality traits. A person's behaviour may vary considerably if they are aware of cyberbullying (Shaikh et al., 2021). According to the Theory of Planned Behaviour, people's attitudes about behaviour develop from their behavioural beliefs. Positive attitudes are valued toward activities that we feel will lead to desired outcomes, whereas negative attitudes are addressed toward behaviours that we believe will lead to primarily undesirable outcomes. Studies that focused on traditional bullying looked at the predicting power of psychological variables. For instance, kids who believe that aggression is acceptable when someone deserves it are more likely to engage in aggressive conduct themselves. It was discovered that there was a correlation between respondents' scores on a "justification of violence" scale, where high scores indicated a propensity for aggression on the part of the respondents, and their participation as a cyberbully (Heirman & Walrave, 2012).

Hypothesis 1: Attitude towards cyberbullying will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions.

Subjective Norms

Subjective norms indicate an individual’s perception of social pressure regarding cyberbullying behaviour. Prior studies examining the predictive value of subjective norm on behavioural indicate that an individua will be motivated to comply with the pressure put on him by others if he believes others think he should perform the behaviour. In contrast, a person will be less driven to engage in inappropriate activity if they believe that others would react negatively to it. It was discovered that peer normative ideas endorsing cyberbullying were substantially correlated with cyberbullying among adolescents (Heirman & Walrave, 2012).

Hypothesis 2: Subjective norms regarding cyberbullying will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions.

Perceived Behaviour Control

Perceived Behaviour Control over cyberbullying may be defined as the ease with which one may be engaged in cyberbullying. Kyobe & Lusinga (2018) report that mobile technology features now make it easy for one to engage in cyberbullying anonymously. Bullies would engage in cyberbullying when they are anonymous which reduces their chances of being identified and

punished. Additionally, because the cyber victim doesn't always provide visual feedback, cyberbullies frequently do not have to be aware of the agony they are creating. The 24/7 accessibility to digital media is another factor that could facilitate cyberbullying in comparison to conventional bullying. This means that potential bullies can now reach their targets regardless of time or place (Heirman & Walrave, 2012).

Hypothesis 3: Perceived behavioural control over cyberbullying will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions

Perceived Social Consequences

The spiral of silence theory contributes to the understanding of why victims of bullying may occasionally feel powerless to intervene. According to the theories, victims of bullying frequently experience increased isolation since they have nowhere to run. Additionally, it has been proposed that because people may choose the information, they receive online, they think they are surrounded by more like-minded people than in actual social settings. As a result, the projection effect will lessen people's anxiety about being alone and encourage them to share their ideas online, reducing the internet's spiral of silence (Akrim & Sulasmi, 2020).

According to this theory, people are less likely to communicate the opinions they believe are unpopular and more likely to speak up about topics they believe are broadly accepted. Fear of social rejection or unfavourable effects is the main reason for this reluctance to voice controversial thoughts. Perceived social consequences, as used in the Spiral of Silence, refer to a person's assessment of how the expression of an opinion may damage their connections, acceptance, or social position within their social or cultural group. When they fear that voicing a different perspective will make them a target for rejection, censure, or isolation, people are more likely to agree with the consensus.

Hypothesis 4: Perceived social consequences will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions.

4. METHODOLOGY AND DATA COLLECTION

To rigorously test the hypotheses derived from the theoretical research framework, the researcher employed an online survey disseminated via Microsoft Forms. Microsoft Forms was deemed the optimal survey software for this research, given that the University of Cape Town provides all its enrolled students with access to Microsoft 365 through the Microsoft Student Advantage Program. The study employed convenience sampling. While convenience sampling might have presented certain limitations, it was deemed suitable for an online survey investigating the factors influencing the prevalence of cyberbullying against students with disabilities in higher education institutions due to its accessibility, cost-effectiveness, and time efficiency. Digital platforms facilitated easy access for participants, allowing them to complete the survey at their leisure and submit their responses electronically.

Typically, the researchers aimed for a 95% degree of assurance (Saunders et al., 2019). The target population for this study were students at the University of Cape Town (UCT), above 18 years old. Students above 18 years did not require any consent from their parents to complete the online survey. Older students are also more likely to have firsthand knowledge of the academic setting and the subject matter being studied, which allowed them to respond with greater depth and knowledge. Also, the online questionnaire would offer some level of safety and anonymity to the respondents. The survey items, measured on a Likert scale (1=strongly disagree – 5 strongly agree), were developed through a systematic review of validated cyberbullying and technology-use instruments reported in prior studies, e.g. Kyobe & Lusinga (2018; Aikins et al (2021); Ganca & Kyobe, 2023). The items were adapted to align with the theoretical constructs of the Theory of Planned Behaviour, ensuring that attitudes, subjective norms, and perceived behavioural control were adequately measured. For instance:

Attitudes were measured using these questions:

Cyberbullying against students with disabilities is morally wrong; Cyberbullying against students with disabilities is not harmful; Condoning cyberbullying against students with disabilities is acceptable.

Subjective norms were measured using these questions:

People important to me believe that cyberbullying against students with disabilities is wrong; My friends think it is important to discourage cyberbullying against students with disabilities; My professors think it is important to discourage cyberbullying against students with disabilities.

Perceived Behavioural Control was measured using these questions: I believe I have the knowledge to prevent cyberbullying against students with disabilities; I feel confident in my ability to intervene if I witness cyberbullying against students with disabilities; I believe I can make a difference in reducing cyberbullying against students with disabilities; I believe that most people in my institution are against cyberbullying of students with disabilities; I believe that expressing disapproval towards cyberbullying against students with disabilities is widely supported in my institution.

Cyberbullying Experience was measured using the following questions: I have experienced or witnessed students with disabilities being cyberbullied in my higher learning institution; I have defended a cyber victim from a cyberbully.

Reporting and Support was measured using the following questions: Reporting instances of cyberbullying at your higher learning institution is effective; Reporting mechanisms available for cyberbullying instances are available; Students are made aware of support systems and resources to students with disabilities who have experienced cyberbullying; Support systems and resources are effective in assisting students who have been victims of cyberbullying.

In adapting these instruments, careful attention was given to contextual relevance for South African higher education institutions, including the language used and the cultural framing of cyberbullying experiences. A pilot study with students was also undertaken to refine wording and response options, which enhanced the clarity and reliability of the instrument. The Department of Student Affairs and the Commerce Faculty Research Ethics Committee approved the research.

Participants had to provide their informed consent before answering the online questionnaire. The research's objectives, participant responsibilities, the right to opt in or out of involvement, the freedom to withdraw at any time without cause were all described in the ethics application. Participants were not asked for any personal information to ensure confidentiality.

5. DATA ANALYSIS

The online survey was conducted over four weeks and responses were recorded in Microsoft Forms. In total, 84 responses were completed. The data was exported into Microsoft Excel and cleaned. There were six incomplete responses which were removed. Each variable was then labelled according to the construct measured.

5.1. Demographic Statistics

The following section outlines the sample demographic data from 78 cleaned responses. Statistica software was used to analyse the demographic data. Statistica software was used for the analysis. Responses by Age – respondents fall in three main groups: 15-25, 26-35 and 36-45 years old. Relating to their gender, there were males, females, No-Binary and those who preferred not to say. 59.74% of the total number of respondents were females followed by males (36.36%). The 'non-binary' counted for only 2.60%, while those who 'Prefer not to say' were 1.30%. Majority of the respondents were non-disabled (74%), while the disabled were 26%.

Table 1.
Descriptive statistics of disabled and non-disabled

Variable	Descriptive Statistics (All respondents – Disabled and non-disabled)				
	Valid N	Mean	Minimum	Maximum	Std.Dev.
Attitude towards cyberbullying	78	4,59829	2,00000	5,00000	0,760419
Subjective Norms	78	4,34615	1,00000	5,00000	0,768128
Perceived Behaviour Control	78	3,55128	1,00000	5,00000	0,947126
Perceived Social Consequences	78	4,17949	3,00000	5,00000	0,613561
Prevalence of Cyberbullying	78	2,26282	1,00000	5,00000	0,999105
RS 16-Reporting of incidences effective	78	3,179487	1,000000	5,000000	0,963538
RS17-Reporting mechanism available	78	2,512821	1,000000	5,000000	1,053671
RS18-Awareness of support systems created	78	2,653846	1,000000	5,000000	1,066940
RS19 -Support systems effective	78	3,217949	1,000000	5,000000	0,783721

Table 2.
Descriptive statistics of disabled only.

Variable	Descriptive Statistics (Disabled respondents				
	Valid N	Mean	Minimum	Maximum	Std.Dev.
Attitude towards cyberbullying	20	4,68333	2,00000	5,00000	0,868386
Subjective Norms	20	4,08333	1,00000	5,00000	1,002191
Perceived Behaviour Control	20	3,33333	1,00000	5,00000	1,048530
Perceived Social Consequences	20	4,17500	3,00000	5,00000	0,612909
Prevalence of Cyberbullying	20	2,30000	1,00000	5,00000	1,043779
RS 16-Reporting of incidences effective	20	3,100000	1,000000	5,000000	1,252366
RS17-Reporting mechanism available	20	1,900000	1,000000	4,000000	0,911910
RS18-Awareness of support systems created	20	2,200000	1,000000	4,000000	0,951453
RS19 -Support systems effective	20	3,250000	2,000000	4,000000	0,638666

5.2. Reliability Testing

Table 3.
Item Reliability Analysis Summary

Construct	Items	Cronbach Alpha
Attitude	2	0.65
Subjective Norm	3	0,68
Perceived Behaviour Control	3	0,85
Perceived Social Consequences	2	0,86
Prevalence of Cyberbullying	2	0,67

While some Alpha scores are below the threshold of 0.70, scores between 0.65 – 0.70 can still indicate reliable data especially in exploratory studies (Sijtsma, 2009; Ursachi et al., 2015)

5.3. Findings and Discussion

Table 4.
Regression Analysis (Disabled and non-disabled)

Regression Summary for Dependent Variable: Prevalence of cyberbullying (PREV)						
R= ,54338114 R^2= ,29526307 Adjusted R^2= ,23570783						
F(6,71)=4,9578 p<,00027 Std.Error of estimate: ,94979 (All respondents - Disabled and not disabled)						
N=78						
	b*	Std.Err.	b	Std.Err.	t(71)	p-va
Intercept			1,071695	1,054838	1,01598	0,31
Attitude toward cyberbullying	-0,233428	0,107312	-0,333503	0,153318	-2,1752	0,03
Perceived behavioural control	-0,103240	0,134533	-0,118424	0,154320	-0,7674	0,44
Perceived social consequences	0,365930	0,129394	0,410507	0,145156	2,82804	0,00
Subjective Norms	0,212375	0,114729	0,300379	0,162270	1,85111	0,06

Table 5.
Regression analysis (Only Disabled)

Regression Summary for Dependent Variable: Prevalence of cyberbullying (PREV)						
R= ,87452362 R^2= ,76479157 Adjusted R^2= ,62758665						
F(7,12)=5,5741 p<,00482 Std.Error of estimate: ,63697						
N=20						
	b*	Std.Err.	b	Std.Err.	t(12)	p-v
Intercept			5,559371	1,783751	3,11667	0,00
Attitude toward cyberbullying	-0,382534	0,180691	-0,427815	0,202079	-2,1170	0,05
Perceived behavioural control	0,040082	0,240208	0,039901	0,23911	0,16687	0,87
Perceived social consequences	0,611299	0,249477	0,582467	0,237711	2,45032	0,03
Subjective Norms	1,062467	0,415372	1,106557	0,432609	2,55787	0,02

The findings in Table 4 indicates that when the responses of all students (disabled and non-disabled) are considered, only attitude towards cyberbullying and perceived social consequences predict the prevalence of cyberbullying on the disabled. For attitude, respondents were asked if "Cyberbullying of disabled students is morally wrong (AT1)", and if "it is acceptable to condone cyberbullying against disabled students (AT2)". The influence of attitude is negative (-0,333503) and is significant suggesting that as attitudes (negative attitude towards cyberbullying increases, the prevalence of cyberbullying decreases. Prevalence was measured as the frequency and magnitude of cyberbullying episodes. In the present study, students were asked to indicate "how often they experienced or witnessed cyberbullying of the disabled students in their institution" and "how often they defended cyberbullying of disabled victims". The descriptive data in Table 1 and 2 show that Prevalence of cyber bullying was below 3 in both cases (mean = 2,26 and 2,300) suggesting low levels of prevalence. Therefore, with a high

negative attitude towards cyberbullying, at this institution, there is low prevalence of cyberbullying. In addition, Table and 2 also show that Perceived Social Consequences has a mean score (mean = 4.17, indicating Agree). Perceived social consequences was measured by asking respondents about their "willingness to speak up against cyberbullying of the disabled" and if "they were not concerned about potential negative consequences". Respondents were willing to speak up and were not concerned about negative consequences. These findings could be attributed to the University effort to address this abuse and existence of some policy to direct this effort.

Subjective norms were measured by asking the students to indicate if people important to them are against cyberbullying of disabled and that friends, teachers and professors discourage victimisation of the disabled. Tables 1 and 2 show that they agree (means 4.34 and 4.08). The regression analysis (of disabled responses only) in Table 5 indicates strong and significant results for Subjective Norms (1,106557). This was also the greatest predictor of prevalence of cyberbullying on the disabled followed by Perceived Social Consequences (0,582467). Table 5 also reveals a good regression model whereby (R^2= ,76479157), i.e., 76% of the variance in the dependent variable (Prevalence of cyberbullying among the disabled) is explained by the independent variables. We also run ANOVA to determine if the prevalence of cyberbullying on the disabled differed by the disabled gender and age. No significant results were obtained indicating that both gender and age do not influence the above.

There are however concerns regarding the reporting and support of the incidents relating to victimisation of the disabled. This was measured by questions RS16 - RS19 which all returned low results (see Tables 1 and 2). In the case of RS19, students are not sure if the support systems work! These findings suggest that technology design must consider subjective norms and social consequences, incorporating features such as anonymous reporting tools, embedded awareness campaigns, and peer-support mechanisms within educational platforms. While the findings provide valuable insights, several limitations should be acknowledged. The study was conducted in one institution and relied on self-reported data, which may introduce reporting bias. Future studies could expand the sample, employ longitudinal designs, and explore additional contextual factors to strengthen the generalisability of the results.

5.3.1. Hypotheses Testing

Hypothesis 1: which states that Attitude towards cyberbullying will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions, was only supported when all (disabled and non-disabled students) were considered. It not supported when only the disabled responses were considered.

Hypothesis 2: which states that Subjective norms regarding cyberbullying will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions was strongly supported when only the responses of the disabled were considered.

Hypothesis 3: which states that Perceived behavioural control over cyberbullying will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions, was not supported.

Hypothesis 4: which states that Perceived social consequences will significantly predict the prevalence of cyberbullying against students with disabilities in higher learning institutions, was supported.

6. CONCLUSION

The integration of the Spiral of Silence Theory and the Theory of Planned Behaviour (TPB) offer a good framework for understanding the factors predicting the prevalence of cyberbullying on the disabled in higher education. The Spiral of Silence Theory suggests that individuals may remain silent on controversial issues if they feel their views are in the minority, which can empower bullies and perpetuate the cycle of abuse. Conversely, the TPB highlights how attitudes, subjective norms, and perceived behavioural control influence students' intentions to engage in cyberbullying.

To answer the main research question, the present study found that Subjective Norms predicted cyberbullying prevalence the most, followed by Perceived Social consequences. Therefore, the institution should encourage subjective norms and encourage building of strong social connections to mitigate the effects of cyberbullying on the disabled. Attitude towards cyberbullying appears not to be a significant predictor for the disabled respondents. This is not consistent with earlier studies that have found better attitudes and acceptance to lead to building preventive and coping mechanisms for the vulnerable (Bourke & Burgman, 2010; Cuadros & Berger, 2016; Wood & Orpinas, 2021). There appears to be issues with the support mechanisms and reporting of cyberbullying incidents in this institution. While policies to prevent victimisation of the disabled exist in the institution, implementation does not appear to have been done effectively. According to (Campbell, 2018) teachers and school management need to build trust among students if they are to report cyberbullying incidents often. They also have to develop the ability to interpret school policies and procedures consistently. Many writers indicate that the development and implementation of anti-cyberbullying policies require awareness of the legislation, having a clear definition of cyberbullying, clear rules regarding the use of technology, and prevention measures and interventions (Gillespie et al., 2018; Pennell et al., 2020; Smit, 2015). Kowalski & Toth (2017) also found that few students with disabilities told someone about being cyberbullied, some would rather confide in their parents and therapists and over a third of their responding groups did nothing in response to being cyberbullied which is concerning.

We also found that Age and Gender did not discriminate the influence on prevalence of cyberbullying against students with disabilities. Similar findings have been reported in related studies (Barringer-Brown, 2015). However, Emerson et al. (2022) found that the association between disability and risk of exposure to peer cyber victimisation is moderated by gender.

This relationship should be investigated further. The results underscore that cyberbullying prevention is not only a matter of policy but also a matter of technology design and education. Designers of educational technologies must integrate safeguards, awareness prompts, and supportive reporting mechanisms, while educators must embed responsible mobile and digital technology use into curricula.

6.1. Limitations and Recommendations for Future Research

This study has several limitations. The theories used to build the conceptual model are limited. There are many other factors not considered. Future studies should expand on this model to include other relevant predictors. The study primarily focused on students in higher education, which may restrict the generalizability of the findings to other age groups or educational contexts. Furthermore, the cross-sectional design only captures a snapshot of cyberbullying, limiting the under-standing of how attitudes and behaviours evolve over time. Future research should aim to diversify samples across different age groups and educational settings. A longitudinal design would provide more insights into changing attitudes and behaviours of students. Incorporating qualitative methods, such as interviews or focus groups, could deepen the understanding of individual motivations and perceptions. Lastly, subsequent studies should test the efficacy of specific interventions or educational programs designed to mitigate cyberbullying, building on the foundational insights gained from this research.

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Finding the Heart of Design and Technology

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Abstract

A primary goal of Technology Education is the suitable development of one's Technological Capability. Technological capability is defined as the dynamic combination of ability and motivation that goes beyond mere understanding to enable creative, high-quality outcomes. It involves self-directed, adaptive engagement with complex tasks, where learners apply judgement, take risks, and learn from experience, especially in uncertain or unfamiliar contexts. A balanced approach to technological capability involves the integration of all three domains of learning: Head (cognition), Hand (skills), and Heart (affective). The affective domain of learning plays a crucial role in shaping students' engagement, motivation, and wellbeing in design and technology education. However, its treatment in design and technology subject specifications appears to be less explicitly addressed than the cognitive and psychomotor domains. While learning outcomes often focus on problem-solving, designing, and craft-based activities, there is limited emphasis on fostering emotional and values-driven competencies such as empathy, fulfilment, and a sense of belonging; despite an increasing recognition of the importance of emotion in the design sector. This paper searches for the 'Heart' of design and technology and presents a scoping review of the literature on the affective domain. By synthesising key findings, this study aims to highlight best practices, challenges, and opportunities for embedding the affective domain more explicitly within technology education curricula. This matters because it shapes how technology is taught and assessed. Design and technology education is more than knowledge transfer; it is about fostering excitement, inspiration, and emotional engagement.

Keywords: *affective learning domain, design and technology education, holistic learning, scoping review.*

1. INTRODUCTION

The affective domain is directly related to Bloom's Taxonomy, which was originally developed in 1956 by Benjamin Bloom and his colleagues to classify educational objectives into three domains: *cognitive*, *affective*, and *psychomotor* (Bloom, 1956). While Bloom primarily focused on the cognitive domain (knowledge and intellectual skills), the affective domain was later expanded upon by David Krathwohl, who was one of Bloom's collaborators. Krathwohl's taxonomy of the affective domain mirrors the hierarchical structure of Bloom's cognitive taxonomy. It describes levels of emotional involvement and value internalisation, moving from *receiving* (awareness) to *responding* (active participation), to *valuing* (attaching worth), to

organisation (integrating values), to *characterisation* (consistent value system) (Krathwohl et al., 1964). This paper refers to the affective domain as 'heart' related activities, the alignment of volition or will, motivation, emotions and values resulting in feelings of wellbeing, with the 'head' characterising the cognitive and 'hand' the psychomotor domains completing the popular metaphor for holistic activity.

Outside of academic papers there are many examples of popular books written about motivation and emotions; there is a growing understanding of the important link between working with our hands and the effect it has on our emotions. Pink (2011) in his book 'Drive' challenges traditional notions of motivation driven solely by external rewards. Pink suggests that there are three key elements which play a significant role in fostering intrinsic motivation: *autonomy*, *mastery*, and *purpose*. Pink argues that understanding and harnessing these intrinsic motivators, individuals and organisations can create a more engaging and fulfilling environment that promotes long-term growth and achievement. Ploszajski (2021) in her book 'Hand Made: A Scientist's search for meaning through making' describes how in times of deep discontent she would throw pots of clay on a pottery wheel, where the point was to be involved in the making process, to enjoy it without the pressure to have a successful outcome. The actions and processes offered peace of mind and contentment, an emotional response. Crawford (2009) in his book "The Case for Working with Your Hands" explores 'wholehearted' activities and advocates skilled manual work as a means of finding fulfilment which offers a tangible sense of accomplishment and a deeper engagement with the physical world; there is a satisfaction and autonomy that can arise from mastering practical skills. More recently, "Head, Hand and Heart" has emerged in the work of Goodhart (2020), where they divide human aptitudes into three: *head* (cognitive), *hand* (manual and craft) and *heart* (caring, emotional). Goodhart argues that a healthy society must redefine the notion of skilled work to equally value those who engage with their hands and hearts, alongside those who work primarily with information and data.

In design and technology (D&T) subjects, students learn knowledge and skills through the interaction of the cognitive activities using the 'head' and the craft-based activities using the 'hand', whereby the quality of the process and the outcome can be measured and graded by teachers and examiners. What is more difficult to measure is what is *experienced* during this learning process. During these cognitive and psychomotor activities, students also experience 'heart' related emotions such as enjoyment, excitement, frustration, empathy, and feelings of fulfilment and a sense of belonging. In an attempt to explain what is meant by the 'heart' related experiences in learning we can turn to Dewey (1933, p. 189) who posited that there "is no education when ideas and knowledge are not translated into emotion, interest, and volition". Understanding emotions, interests, and volition could provide insight into the factors that drive individuals to engage with or acquire knowledge, particularly when it leads to a sense of gratification or contentment. The internal sense of reward and satisfaction experienced through purposeful and tangible accomplishments is described here as "heart" based learning.

A reading of the Assessment of Performance (APU) D&T model diagram, "The Interaction of Mind and Hand" (Kimbell & Stables, 1991), may initially suggest that it refers solely to the interaction between the psychomotor and cognitive domains. However, a closer examination particularly of their chapter on capability, clearly indicates that the affective domain has always been present. It is reflected in what occurs *during* the interaction of mind and hand, and in the

motivations that underlie thought and action. Kimbell and Stables describe capability in D&T as "the power to produce change and improvement in the made world" (p. 18). They further emphasise that "embedded in the concept of capability is that of potential – and here we find reference to the uniqueness of mankind – that capability is both developed and demonstrated by the human motivation to change and improve" (p. 19). In Figure 1, "The Interaction of Head, Hand and Heart" (Plunkett & Dunbar, 2025), the 'hand' can be attributed to the psychomotor domain while the 'mind' could be described as having attributes of both the cognitive and affective domains. The APU D&T model diagram has been adapted to include a heart symbol illustrating the affective domain, combined with the cognitive (head) and psychomotor (hand) domains. Figure 2, "Balanced technological capability" (Plunkett & Dunbar, 2024) represents an equal treatment of the three domains of learning.

FIGURE 1. *The Interaction of Head, Hand and Heart:*
(adapted from the APU design and technology model diagram, "The Interaction of Mind and Hand" (Kimbell et al., 1991): Head: Cognitive, Hand: Psychomotor and to unpack what is meant by 'Heart' which represents affective skills.

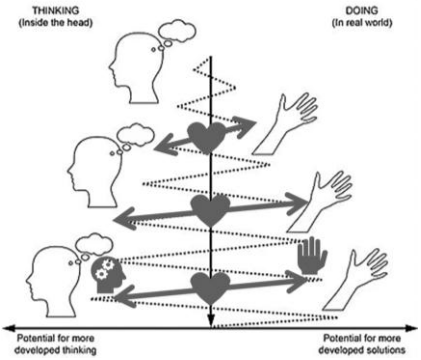
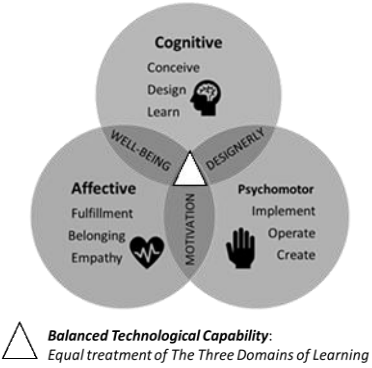


FIGURE 2. *Balanced Technological Capability; equal treatment of the three domains of learning.*



2. LITERATURE REVIEW

Mitcham's (1994) philosophical framework supports this perspective by categorising technology not only as object, knowledge, and activity, but also as volition—the will or intent behind technological engagement. This reinforces the notion that emotional and motivational aspects are inseparable from technological activity. He distinguished technology as an object based on the nature of the objects such as tools or machines, as knowledge based on the types of knowledge such as rules or theories, as activity based on the types of actions such as making or using, and as volition based on types of will such as active or perceptive will.

Building on these ideas, McLain et al. (2019) argue that technological human activity is inherently linked to both technological innovation and determinism and is deeply intertwined with social activity. They emphasise the value of design and technology education as a cultural subject, rather than merely a technical or economic one. This perspective aligns with the concept of 'intelligent action,' which connects thought and action in the process of designing and making, as discussed by Kimbell et al. (1996). The integration of reflection and action, as Biesta (2017) suggests, is central to knowledge creation and especially relevant to D&T tasks that combine doing with thinking.

Human existence has fundamentally depended on technology, with the processes of creating, designing and adapting to enhance our lives being inherently natural (Petrina, 2007; McLaren, 2019). Whether perceived as 'work' or 'play,' the role of learning through play remains significant across the human lifespan (Stables, 1997). While play-based learning (Roberts & Knaus, 2023) is instinctive and essential for children, the inclination to engage in play tends to diminish as individuals mature, often rendering learning as a taxing task. Nevertheless, there is a discernible trend of adults re-engaging with learning through hobbies and activities that fall outside the realm of daily responsibilities or professional obligations. This re-engagement is akin to the deliberate planning of recreational activities, such as sports, which, though once integral to daily life, now require conscious scheduling (Williams, 2009). The evolving nature of play and learning from childhood to adulthood, highlights the continued, albeit transformed, importance of these activities in human life. It is natural for humans to explore, learn, adapt, and improve (Keirl, 2015).

When empathy becomes embedded in the design process, it not only strengthens human connection but can also foster creativity and lead to more impactful outcomes (Demetriou & Nicholl, 2022). This affective engagement is further highlighted in Jones' (2023) systematic review 'Interaction with end-users in design and technology education' which explores the implications of the interaction of young designers with end-users in D&T. Many of the studies in the systematic review reported increased experiences of motivation and confidence amongst the students. Students experienced 'excitement' especially during activities which involved 'meaningful' interactions between students and the real-life end-user; they developed feelings of empathy from their interactions with the end-user. These *feelings* are not merely abstract or sentimental; they have a physical basis and can be scientifically measured. Prosocial experiences such as empathy and feeling good are linked to the release of neurochemicals like oxytocin, dopamine, and serotonin, which enhance mood and support social bonding (Keltner et al., 2014).

There is growing recognition that the affective domain, which includes emotions, values, attitudes, and dispositions, is essential to meaningful and holistic learning (e.g. Acosta & Diego, 2025; Doo & Kim, 2024; Bowden, Tickle & Naumann, 2019). The cognitive and psychomotor domains in design and technology education are evident through measurable outcomes such as knowledge acquisition, technical skill, and assessed performance. The affective domain is less easily captured through traditional academic metrics (e.g. Viccaro, 2024), yet it has a critical role in shaping student engagement and capability. This makes it a potential area for future research as an area typically overlooked in assessment. As education increasingly moves toward approaches that prioritise the learner and emphasise values, the affective domain has received more attention in theory. In D&T education, where creativity, ethical thinking, and personal engagement are central, the affective domain plays a critical role in shaping student motivation and deeper, balanced learning. This paper therefore presents a scoping review to identify the treatment of the affective domain in the research base relevant to the subject area of D&T education.

3. METHODOLOGY

Rationale

Mak and Thomas (2022) describe a scoping review is a form of knowledge synthesis that employs a systematic and iterative methodology to examine the breadth and scope of existing or emerging literature on a particular topic. The primary objectives of conducting a scoping review are to map the extent, range, and nature of the available evidence and to identify gaps in the current body of knowledge. Notably, scoping reviews are inclusive of various sources of evidence and are not confined to peer-reviewed literature. While similar to a systematic review in its emphasis on transparency and methodological structure, a scoping review is less rigid and rigorous, as its primary purpose is to map the existing body of evidence and identify areas requiring further research (Grant & Booth, 2009). Kitchenham's (2004) step by step guide for conducting reviews is used to structure the stages and activities:

(i) Stage 1: Planning the review
Activity 1.1: Identification of the need for a review
Activity 1.2: Development of a review protocol
(ii) Stage 2: Conducting the review
Activity 2.1: Identification of research
Activity 2.2: Selection of primary studies
Activity 2.3: Study quality assessment
(iii) Stage 3: Reporting the review
Activity 3.1: Communicating the results

Stage 1: Planning the review

Activity 1.1: Identification of the need for a review

The identification of the need for a review has been outlined in the Introduction and Literature review sections.

Activity 1.2: Development of a review protocol

This scoping review explores the emergence of and engagement with the affective domain in D&T education. As a starting point, a search of the Education Resources Information Centre (ERIC) database was conducted. In line with the broad approach typical of scoping reviews, filters such as 'Peer reviewed' and 'Full text available on ERIC' were not applied. The initial search used the terms ‘affective domain’ and ‘design and technology’ to assess the scope of the research area. Results from this search are presented in Table 1. The filter ‘Secondary Education’ was initially considered but later excluded, as it risked omitting studies related to the transition from primary to secondary education. Articles under ‘Technology Education’ often referred to educational technology rather than D&T as a subject, prompting the addition of ‘Design’ to refine results. Table 2 shows the number of relevant articles over a 20-year period, while Table 3 highlights the most frequent sources (excluding those with fewer than 10 articles). Given that the *International Journal of Technology and Design Education (IJTDE)* produced the largest number of publications (112), we focused further analysis on how the affective domain is addressed within this journal. Data was collected in May 2025. ERIC has a limited ‘publication date’ of ‘last 20 years’ only.

TABLE 1. *Results of initial searches on ERIC (May 2025)*

Descriptor	Search Terms	2025	Since 2024	Since 2016 Last 10 yrs	Since 2006 Last 20 yrs	Total
Technology Education Secondary Education	Affective domain design and technology	2	17	98	208	219
Technology Education	Affective domain design and technology	4	42	337	801	1083
Technology Education Design	Affective domain design and technology	2	14	121	272	339

TABLE 2. *Results of initial searches on ERIC – Publication Dates (May 2025)*

Publication Date	Results
In 2025	2
Since 2024	14
Since 2021 (last 5 years)	48
Since 2016 (last 10 years)	121
Since 2006 (last 20 years)	272

TABLE 3. *Results of initial searches on ERIC – Sources (May 2025)*

Source	Results
International Journal of Technology and Design Education	112
Design and Technology Education	48
Journal of Technology Education	23
Technology and Engineering Teacher	23
Technology Teacher	16
Journal of Design and Technology Education	11
National Center for Engineering and Technology Education	11
ProQuest LLC	10

Stage 2: Conducting the review

Activity 2.1: Identification of research

As part of developing a review protocol, data was collected from the journal with the most resulting articles in the initial search for relevant literature: *IJTDE*. The ERIC (Education Resources Information Centre) database was chosen for its comprehensive coverage of education-related literature, including both research and practice-based publications. In line with the broad, exploratory nature of a scoping review, filters such as 'peer reviewed' were not applied. The search focused on the *IJTDE* using terms related to the affective domain; "affective", "volition" and "empathy" returning 34 results. This paper recognises that many publications will not necessarily include the word 'affective" in their title but it may be referred to in the abstract. To address this, words related to the affective domain were considered for inclusion in the search terms. As discussed in the literature review, Mitcham's (1994) philosophical framework categorises technology not only as object, knowledge, and activity, but also as "volition"—the will or intent behind technological engagement. Also "empathy" emerges as a pivotal concept in design research, shown to enhance human connection, creativity, and student engagement through meaningful end-user interactions. This resulted in the following search terms**:** abstract: (affective OR volition OR empathy) AND design AND technology; journal articles; *IJTDE*.

Activity 2.2: Selection of primary studies

Articles were selected based on the relevancy of their titles and abstracts, since 2006 (last 20 years). The articles were synthesised by examining abstracts and relevant full texts to identify affective themes; the inclusion of affective related terms supports a comprehensive and unbiased synthesis of the literature.

To focus the research the following inclusion criteria (IC) and exclusion criteria (EC) were developed to determine which articles would be included in this review:

- **IC1:** The article reports on research into the affective domain of learning in "design and technology" education at primary or secondary school level. The article title may not refer to 'affective domain' but the abstract refers to 'affective' or 'volition' or 'empathy'.
- **EC1:** Articles which are focused on the use of technology rather than D&T: Artificial Intelligence, Computer Software, Computer Science and educational technology.

4. RESULTS

Activity 2.3: Study quality assessment

Table 4 indicates the number of studies (n=13) which were included when the exclusion criteria were applied.

TABLE 4. *Resulting articles when exclusion and inclusion criteria were applied*

No.	Title	Authors	Year
1	Using Empathy Maps to Support Design-Thinking Enhanced Transdisciplinary STEM Innovation in K-12 Setting	Wing-Leung Yeung; Oi-Lam Ng	2024
2	A Deep Dive into the Impacts of Empathy on Design Learning and Teaching	Pelin Efilti; Koray Gelmez	2024
3	The Roles of Empathy and Motivation in Creativity in Design Thinking	Xinyu Li; Juanjuan Chen; Hongjie Fu	2024
4	Primary School Students' Understanding of the Manifestations of Technology	Johan Lind; Eva Davidsson; Mats Lundström	2024
5	Effects of Association Interventions on Students' Creative Thinking, Aptitude, Empathy, and Design Scheme in a STEAM Course: Considering Remote and Close Association	Zehui Zhan; Xiao Yao; Tingting Li	2023
6	Towards a Signature Pedagogy for Design and Technology Education: A Literature Review	Matt McLain	2022
7	Developing an Instrument for Assessing Technology Teachers' Understandings of the Nature of Technology	P. John Williams; Jianjun Gu	2022
8	Students' Attitudes toward Technology: Exploring the Relationship among Affective, Cognitive and Behavioral Components of the Attitude Construct	Johan Svenningsson; Gunnar Höst; Magnus Hultén; Jonas Hallström	2022
9	The Mitcham Score: Quantifying Students' Descriptions of Technology	Svenningsson, Johan	2020

10	Pre-School Children's Expressed Technological Volition during Construction Play	Kristina Thorshag; Mona Holmqvist	2019
11	Alignment of the Traditional Approach to Perceptions and Attitudes with Mitcham's Philosophical Framework of Technology	Piet Ankiewicz	2019
12	Contextmapping in Primary Design and Technology Education: A Fruitful Method to Develop Empathy for and Insight in User Needs	Klapwijk, Remke; Van Doorn, Fenne	2015
13	Motivating Children to Learn: The Role of Technology Education	Campbell, Coral; Jane, Beverley	2012

Stage 3: Reporting the review

Activity 3.1: Communicating the results

Table 4 displays the results of the final sampling arranged in chronological order. As part of the process a table with a more detailed synopsis and direct quotes of each paper was created (not included with this paper due to the conference page limit, but available from the corresponding author). The searches included papers over the last 20 years (since 2006) however in this scoping review the search criteria resulted in articles which were published in *IJTDE* since 2012. There has been a growing recognition of the importance of the affective domain, encompassing emotions, values, attitudes, and dispositions, in supporting meaningful and holistic learning. This shift has become especially noticeable since 2019. The articles are discussed in the following section.

5. DISCUSSION

The reviewed literature highlights a growing emphasis on the affective domain in D&T education, particularly in relation to learner motivation, emotional engagement, and the development of human-centred competencies. Researchers have explored across a diverse range of contexts and age groups, how affective experiences shape students' understanding, creativity, and attitudes toward technology. Results indicate that emotional and motivational factors are critical to meaningful learning in this field.

The pedagogical value of tools designed to support emotional connection with users and design contexts is demonstrated in a number of the studies included in the review. For instance, empathy maps (Yeung & Ng, 2024) and context-mapping (Klapwijk & Van Doorn, 2015) are shown to help learners connect more meaningfully with real-world users, enhancing both engagement and creativity. Similarly, association-based interventions (Zhan et al., 2023) foster creative thinking and emotional responsiveness, helping students to generate more original and socially aware design solutions. These tools function not only as instructional supports but also as mechanisms for integrating emotional understanding with cognitive design processes.

Motivation emerges as a central theme across many of the reviewed studies. Campbell and Jane (2012) observed that enjoyment, task satisfaction, and social interaction were key motivators for primary students engaging in technology activities. This was echoed in findings by Li et al. (2024) and Thorshag and Holmqvist (2019), which suggest that even very young children exhibit intrinsic motivation and purposeful action when engaged in hands-on, meaningful tasks. These insights point to the importance of designing learning experiences that are emotionally rich and personally relevant to students, as such conditions support deeper, more sustained engagement.

There is an apparent consensus that affective understanding is not only beneficial for student wellbeing but foundational to creativity. Efilti and Gelmez (2024) and Li et al. (2024) indicate that emotional sensitivity and motivation directly support students' abilities to generate novel ideas in design contexts. Li et al.'s explanatory model shows that intrinsic motivation, linked to attention, relevance, and confidence, mediates the relationship between emotional engagement and creative output. These findings support a more integrated approach to learning, where affective, cognitive, and behavioural components work in synergy.

Research in this area also highlights the importance of purposeful pedagogical design and curriculum development. Several studies underscore the role of teacher facilitation, structured dialogue, and reflective classroom practices in supporting students' emotional engagement and technological understanding. For instance, work by Li et al. (2024) demonstrates how teacher-led activities help primary pupils move beyond surface-level conceptions of technology to engage with its multiple manifestations, including knowledge, activity, and volition. Validated tools such as the Basic Empathy Scale (Zhan et al., 2023) and the Mitcham Score (Svenningsson, 2020) offer promising methods for assessing affective dimensions of learning and refining instructional practice accordingly.

The literature suggests a broader conceptual shift within D&T education. McLain (2022) argues for a signature pedagogy grounded in project-based learning and values such as collaboration, iteration, and problem-solving; traits that are deeply rooted in the affective domain. Similarly, Svenningsson et al. (2022) found that students' interest in technology and their attitudinal orientations, particularly among girls, have significant implications for educational practice and long-term engagement. Taken together, these studies reaffirm that affective learning is not a peripheral concern but a fundamental aspect of effective D&T education, one that must be explicitly acknowledged and embedded in both teaching and curriculum design.

6. CONCLUSION

This review of recent international literature reveals a clear and growing recognition of the importance of the affective domain in D&T education. Far from being peripheral or 'soft' skills, affective dimensions are shown to be central to fostering creativity, engagement, and meaningful learning experiences. Emotional connection, purposeful action, and social awareness are closely tied to how pupils engage in design processes and interpret technological challenges.

Studies across a range of contexts and age groups demonstrate that when affective learning is intentionally embedded into curriculum and pedagogy through tools like mapping activities,

association interventions, and context-rich design tasks; pupils not only deepen their conceptual understanding of technology but also produce higher-quality and more socially responsive design work.

The development of validated instruments to assess teachers' and pupils' understandings points to a maturing field that values not just what learners know, but how they feel, act, and relate to the world through technology. These insights call for teacher education and curriculum development that explicitly integrates affective learning, ensuring that future D&T education empowers pupils to think critically, connect authentically, and engage meaningfully in shaping the technological world.

7. LIMITATIONS OF THIS SCOPING REVIEW

Despite the valuable insights gained from this review, several limitations must be acknowledged. The scope of the literature was limited to articles published in the *IJTDE*, which, while highly relevant, may have excluded pertinent studies published in other journals. Although the affective domain is receiving increased attention, much of the literature has emerged since 2019, limiting the ability to assess long-term patterns or sustained impact. There is also considerable variation in how the affective domain is defined and operationalised across studies, some focusing on empathy, others on motivation or values, making synthesis and comparison more complex. Research specifically examining how the affective domain is embedded in teacher education remains particularly scarce, despite its recognised importance. Also, most studies originated from Western or East Asian contexts, cultural and contextual diversity is limited, which may affect the broader applicability of findings. These limitations underscore the need for more comprehensive, empirically grounded and globally inclusive research in this area, including a systematic evidence review to extend this scoping review**.**

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The Impact of Integrating STEAM on Youth Attitudes Towards Technology: A Narrative Literature Review

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Abstract

The integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) into classroom activities plays a crucial role in shaping young people's attitudes toward technology education. By combining disciplines, STEAM fosters critical thinking, problem-solving, creativity, and collaboration. These approaches increase engagement and motivation while also helping reduce gender stereotypes and encouraging more equitable participation of girls in scientific and technological fields.

This article presents a narrative literature review of 45 studies published between 2014 and 2025, focusing on student attitudes, engagement, creativity, and interdisciplinary learning. Studies were analyzed thematically across five categories: conceptual clarity, student motivation, interdisciplinary skill development, the role of the Arts, and conditions for effective implementation.

Findings show that STEAM approaches, particularly those grounded in real-world problems, are effective in enhancing outcomes and engagement. Yet the review also highlights the need for stronger empirical evidence to confirm these impacts. This gap is especially pressing in Québec, where STEAM integration remains limited and little research has examined how such approaches align with local curricula and cultural contexts. Evidence further indicates that students engaged in STEAM develop more positive and confident attitudes toward design and technology, which can shape academic pathways and career choices.

In conclusion, embedding STEAM into educational programs is essential for preparing well-rounded individuals equipped to thrive in a technologically advanced society. Its positive influence on student attitudes underscores the importance of continued research and sustained investment - particularly in Québec, where opportunities exist to build STEAM integration from the ground up.

Key Words: STEAM, Integration, Motivation, Attitude

1. INTRODUCTION

In an increasingly digital and technologically driven world, STEAM education plays a crucial role in enabling young learners to understand, apply, and critically engage with technological systems and processes. As societies face complex global challenges, from climate change to rapid automation, education systems are under pressure to equip students not only with technical knowledge but also with the creative and critical thinking skills needed to navigate uncertainty (Psycharis, 2018; Perignat & Katz-Buonincontro, 2019). In this context, the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) into educational curricula has emerged as a promising pedagogical approach (Aguilera & Ortiz-Revilla, 2021; Costantino, 2018).

STEAM education seeks to break down traditional disciplinary silos by fostering transdisciplinary learning experiences that are rooted in real-world problems. By incorporating the Arts alongside STEM subjects, STEAM aims to cultivate a more holistic set of competencies, including creativity, empathy, and communication, in addition to scientific and technological literacy (Hunter-Doniger, 2021; Chung & Li, 2021). This integration is particularly relevant in shaping students' attitudes toward technology, as it provides more inclusive and engaging pathways into fields that have historically been perceived as abstract, rigid, or inaccessible - especially for girls and students from underrepresented backgrounds (Kijima & Sun, 2021; Vartiainen, 2021).

Despite growing interest in STEAM education globally, its implementation remains uneven, and its conceptual foundations are still evolving (Chappell et al., 2025; Wu et al., 2021). In Quebec province, for example, STEAM has yet to be fully embedded into formal curricula, and empirical research on its impact remains limited. This article addresses this gap by conducting a narrative literature review of 45 studies that examine the effects of STEAM integration on youth attitudes toward technology. The review explores how STEAM influences motivation, engagement, and confidence, and how it contributes to the development of transdisciplinary and 21st-century skills.

By synthesizing findings from various educational contexts, this review aims to provide educators, policymakers, and researchers with a clearer understanding of the transformative potential of STEAM education. It also highlights the conditions necessary for its successful implementation and identifies areas where further research is needed, particularly in the Quebec context.

2. METHODOLOGY

This study adopts a narrative literature review (Green et al.2006 ; Sukhera, 2022) approach to explore how the integration of STEAM education influences youth attitudes toward technology. Unlike systematic reviews, which follow rigid protocols and aim for exhaustive coverage, narrative reviews allow for a more flexible and interpretive synthesis of diverse sources. This approach is particularly suited to emerging fields like STEAM education, where conceptual definitions and implementation practices vary widely across contexts. Artificial intelligence based language tools were utilized to assist in the revision of this manuscript, specifically to improve orthographic accuracy and enhance the clarity and fluidity of the writing.

2.1. Selection of Sources

The review is based on the analysis of 45 research studies published between 2014 and 2025. These studies were selected for their relevance to the integration of STEAM in formal and informal educational settings, with a particular focus on student attitudes, engagement, creativity, and interdisciplinary learning. The sources include empirical studies (qualitative, quantitative, and mixed-methods), conceptual essays, and systematic reviews. They span a wide range of educational levels (from early childhood to higher education) and geographic contexts (North America, Europe, Asia, and others).

2.2. Inclusion Criteria

For inclusion, studies needed to:

- Refer directly to STEAM (or related approaches);
- Focus on student outcomes, particularly attitudes toward technology, science, or interdisciplinary learning;
- Empirical or conceptual contributions relevant to classroom implementation;

Based on these criteria, primary analyses focused on eight dimensions, with verification carried out using a simple true/false coding scheme. The review of the 45 studies summarized in Annex A highlights a clear gradient in the proportion of outcomes reported. Classroom implementation stands out as the most consistently observed dimension, documented in 84.4% of the studies. This is followed closely by problem resolution, which showed positive effects in 80.0% of the cases. Creativity enhancement (71.1%) and critical thinking (73.3%) also received strong support, forming a second cluster of frequently reported outcomes.

By contrast, the attitudinal and social dimensions appear less consistently across the literature. Positive attitudes towards science were reported in 66.7% of the studies, while attitudes towards

technology and towards the arts each reached 60.0%. Social skills showed the lowest proportion, with 57.8% of the studies highlighting improvement in this area.

Taken together, these findings establish a ranking of evidence in which classroom implementation and problem resolution are most consistently reported, followed by creativity and critical thinking, and finally the attitudinal and social outcomes, which remain positive in a majority of studies but with comparatively lower frequency. Figure 1 synthetizes the proportion of all dimensions treated across 45 studies retained for our analysis.

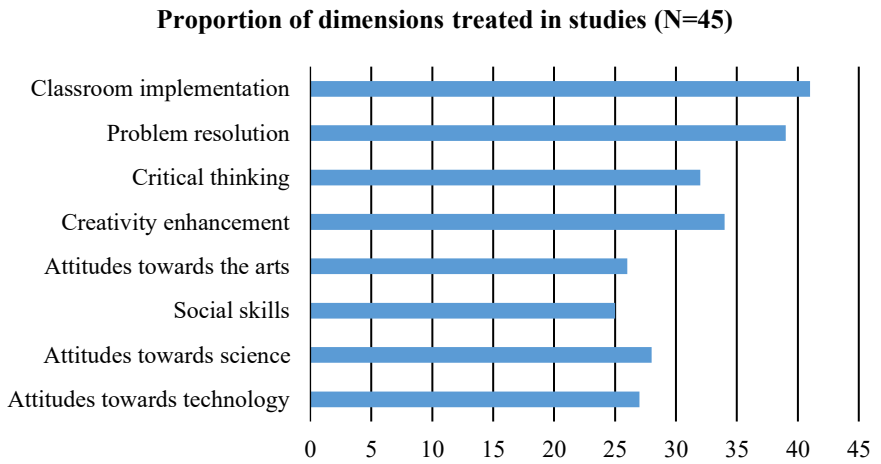

Figure 1. Proportion of dimensions treated in retained studies

2.3. Analytical Approach

The analysis followed a thematic synthesis approach. Following an initial comprehensive reading of all studies, key themes were identified and organized into five overarching categories:

1. Conceptual clarity and ambiguity of STEAM;
2. Impact on student attitudes and motivation;
3. Development of interdisciplinary and 21st-century skills;
4. Role of the Arts in enriching learning experiences;
5. Systemic conditions for successful implementation.

Each theme was examined with respect to recurring patterns, point of divergence, and illustrative case studies. Particular emphasis was place on understanding how STEAM approaches influence students' perceptions of and engagement with technology, as well as the pedagogical strategies that support these outcomes.

3. FINDINGS

3.1. Conceptual Ambiguity of STEAM

A prominent and a recurring theme in the literature is the lack of a clear and shared definition of what constitutes STEAM education. While the acronym suggests an integration of Science, Technology, Engineering, Arts, and Mathematics, numerous studies highlight that this integration is often superficial or inconsistently implemented. In particular, the role of the Arts, where the "A" in STEAM, is frequently instrumentalized to support other school subjects rather than being recognized and engaged as a domain of knowledge in its own right.

Several literature reviews (e.g., Perignat & Katz-Buonincontro, 2019; Aguilera & Ortiz-Revilla, 2021) point out that the Arts are often used to decorate or illustrate STEM concepts, rather than to contribute epistemologically through critical thinking, narrative, or aesthetic inquiry. This phenomenon, sometimes referred to as "arts-washing," risks undermining the transformative potential of STEAM by reducing the Arts to a motivational or visual aid.

Although certain studies advocate more integrated and transdisciplinary models, where disciplines merge around shared epistemologies and pedagogical goals, such approaches remain relatively rare and often experimental. For instance, Sochacka et al. (2016) and Chappell et al. (2025) describe collaborative studios environments in which students and educators from the arts and engineering co-construct knowledge, challenging conventional disciplinary boundaries. However, such initiatives are typically context-specific and difficult to scale.

The lack of a unified theoretical framework further complicates teacher training, curriculum development, and assessment practices. Variants such as STREAM (adding Reading or Religion) or iSTEM (integrated STEM) contribute to conceptual ambiguity, making it harder for educators and policymakers to communicate and implement STEAM effectively.

In sum, while STEAM is widely recognized as a promising and innovative educational approach, its conceptual foundations remain fragile. The literature underscores the need for the development of shared epistemological frameworks, explicit curricular models, and authentic assessment tools that recognize the full value of each discipline, especially the Arts, as integral contributors to knowledge and learning.

3.2. Positive Impact on Student Attitudes

Toward Technology

A central finding across the reviewed literature is that STEAM education has a significant and positive influence on students' attitudes toward technology. By embedding technological learning within creative, collaborative, and real-world contexts, STEAM approaches help demystify

technology and make it more accessible, particularly for students who may not initially identify with STEM fields.

Numerous studies report that students exposed to STEAM activities demonstrate greater motivation, curiosity, and confidence when engaging with technological tools and concepts (Lin & Chang, 2025; Arango-Caro et al., 2025). These effects are particularly pronounced when students are involved in hands-on, project-based learning that integrates design thinking, digital fabrication, or coding within artistic or socially relevant challenges.

Importantly, STEAM education also contributes to reducing gender stereotypes and increasing the participation of girls in technology-related learning. For example, Kijima & Sun (2021) found that girls who participated in a STEAM workshop involving design thinking and social innovation reported increased creative confidence and a stronger sense of belonging in technological environments. Meeting female role models in science and engineering further reinforced their interest in pursuing STEAM careers.

Furthermore, the integration of the Arts plays a key role in making technology more relatable and meaningful. When students are encouraged to use technology as a medium for storytelling, cultural expression, or social critique, they are more likely to see its relevance to their lives and communities. This shift in perception fosters a more inclusive and human-centered view of technology, which is essential for broadening participation in the digital age.

While the literature highlights these positive trends, it also underscores that the depth of impact depends on the quality of implementation. Programs that are well-supported, contextually grounded, and pedagogically coherent tend to produce stronger outcomes. Conversely, superficial or tokenistic uses of technology may fail to engage students meaningfully.

In summary, when thoughtfully designed, STEAM education can transform students' relationships with technology, fostering not only technical skills but also a sense of agency, creativity, and purpose in technological learning.

3.3. Development of Interdisciplinary and 21st-Century Skills

One of the most widely reported benefits of STEAM education is its capacity to foster interdisciplinary thinking and essential 21st-century skills. These competencies include creativity, critical thinking, collaboration, communication, and problem-solving—competencies that are increasingly valued in both academic and professional contexts.

Across the reviewed studies, students engaged in STEAM projects demonstrated a greater ability to connect knowledge across disciplines, particularly when learning was anchored in real-world challenges. For instance, projects such as the design of mechanical sculptures (Chung & Li, 2021) or the creation of 3D plant models (Arango-Caro et al., 2025) required students to integrate

scientific understanding, artistic expression, and technological tools. These experiences promote holistic thinking, iterative experimentation and design, thereby aligning learners' cognitive and creative processes with those characteristics of professional innovation and design context.

STEAM also supports the development of soft skills such as teamwork, empathy, and communication. Within collaborative settings, students learn to negotiate roles, share ideas, and provide constructive feedback. Empirical studies, such as Wilson et al. (2021) and Velarde-Camaqui et al. (2024), show that these social dimensions are not peripheral to learning process, especially when students are tasked with co-creating solutions to complex problems.

Furthermore, the creative dimension of STEAM, often driven by the integration of the Arts, promotes students to take intellectual risks, explore multiple perspectives, and express their ideas in diverse formats. This not only enhances their engagement but also nurtures a mindset of innovation and adaptability. As Lin & Chang (2025) demonstrate, students involved in design thinking-based STEAM activities showed significant gains in originality, elaboration, and usefulness of their ideas.

However, the literature also notes that the depth of interdisciplinary integration varies widely. Many projects remain at the level of multidisciplinary or interdisciplinary learning, where disciplines are juxtaposed or loosely connected. True transdisciplinary learning—where disciplinary boundaries are blurred and new forms of knowledge emerge—is still rare and often difficult to implement due to institutional and curricular constraints (Wu et al., 2021; Mejias et al., 2021).

In conclusion, STEAM education offers a powerful framework for cultivating interdisciplinary competence and future-ready skills, provided that it is implemented with intentionality, collaboration, and support for teacher professional development.

3.4. Conditions for Effective STEAM Implementation

While the pedagogical potential of STEAM is widely acknowledged, the literature emphasizes that its success depends heavily on the systemic conditions in which it is implemented. Effective STEAM education requires more than individual teacher initiative or isolated classroom projects, it demands institutional support, professional development, and curricular flexibility.

Empirical Studies consistently highlight the importance of school leadership in fostering a culture that values interdisciplinary collaboration and innovation (Boice et al., 2024; Dell'Erba, 2019). When school administrators actively support STEAM initiatives, by allocating time for planning, encouraging co-teaching, and investing in resources, teachers are more likely to implement meaningful and sustained STEAM practices.

Teacher training represents another critical factor in effective implementation of STEAM education. Many educators report feeling underprepared to design and facilitate STEAM activities, particularly when it comes to integrating the Arts or using emerging technologies (Wu et al., 2021; Veziroglu-Celik et al., 2025). Professional development programs that focus on design thinking, transdisciplinary pedagogy, and authentic assessment are essential for building teacher confidence and competence.

Access to material and digital resources also plays a significant role. Studies from diverse contexts (e.g., Indonesia, Turkey, the U.S.) show that the lack of tools such as maker spaces, digital fabrication equipment, or collaborative learning environments can severely limit the scope and quality of STEAM projects (Liliawati et al., 2018; Leavy et al., 2023). Moreover, rigid curricula and standardized testing regimes often constrain teachers' ability to experiment with interdisciplinary approaches.

At the policy level, several authors call for coherent educational frameworks that recognize and support STEAM as a legitimate and valuable approach. This includes developing national or regional standards for STEAM integration, funding pilot programs, and creating evaluation tools that reflect the complexity of STEAM learning outcomes (Chappell et al., 2025; García-Llamas et al., 2025).

Finally, the literature stresses the importance of community and cross-sector collaboration. Partnerships between schools, cultural institutions, universities, and industry can enrich STEAM education by providing real-world contexts, mentorship opportunities, and access to diverse expertise.

Overall, the successful implementation of STEAM requires a multi-level strategy that aligns pedagogical innovation with institutional, infrastructural, and policy-level support. Without these systemic enablers, STEAM risks remaining a marginal or short-lived initiative rather than a transformative educational paradigm.

3.5. The Role and Value of the Arts in STEAM

One of the most distinctive features of STEAM education is the inclusion of the Arts, not merely as a complement to STEM, but as a discipline with its own epistemological and pedagogical contributions. When authentically integrated, the Arts enrich learning by fostering emotional engagement, cultural relevance, and expressive complexity.

The literature reveals that in the most impactful STEAM projects, the Arts are not used simply for decoration or presentation, but as tools for inquiry, critique, and meaning-making. For example, students have explored social issues such as inequality, pollution, and identity through mechanical sculptures, storytelling, and visual installations (Chung & Li, 2021; Sochacka et al., 2016). These projects demonstrate how artistic practices can deepen students' understanding of

scientific and technological concepts by connecting them to lived experiences and ethical questions.

In addition, the Arts provide alternative modes of thinking and expression that are often underrepresented in traditional STEM education. Artistic processes encourage abstraction, metaphor, intuition, and speculative thinking—skills that are increasingly recognized as essential in fields like artificial intelligence, bioethics, and sustainable design (Costantino, 2018; Graham, 2020). This cognitive diversity supports inclusive learning environments, where students with different strengths and learning styles can thrive.

Studies further show that integrating the Arts can enhance student confidence and participation, particularly among those who struggle with conventional academic tasks. Artistic activities offer multiple entry points into complex content, allowing students to engage through visual, tactile, or performative means. This is especially beneficial for students with learning differences or language barriers (Hunter-Doniger, 2021; McDaniel, 2025).

Furthermore, the inclusion of the Arts often leads to richer forms of assessment, such as reflective journals, public exhibitions, and peer critiques. These methods align with the goals of authentic assessment and support the development of metacognitive and evaluative skills (Wilson et al., 2021; Li & Chung, 2025).

In conclusion, the Arts are not an optional or decorative element in STEAM—they are central to its transformative potential. By legitimizing artistic ways of knowing and creating, STEAM education fosters a more holistic, inclusive, and human-centered approach to learning.

4. DISCUSSION

The findings of this narrative literature review highlight the transformative potential of STEAM education in shaping youth attitudes toward technology and fostering interdisciplinary competencies. However, they also reveal significant conceptual, pedagogical, and systemic challenges that must be addressed to fully realize this potential.

4.1. Reconciling Conceptual Ambiguity with Pedagogical Innovation

A recurrent issue in the literature is the lack of a unified definition of STEAM. This conceptual ambiguity can constraint implementation, teacher training, and policy development. Yet, paradoxically, it also allows for contextual flexibility and innovation. Educators and institutions have adapted STEAM to suit local needs, often blending it with design thinking, sustainability education, or social justice frameworks. This suggests that rather than seeking a rigid definition, the field may benefit from shared guiding principles, such as transdisciplinarity, creativity, and real-world relevance, that can be adapted across contexts.

4.2. STEAM as a Catalyst for Engagement and Equity

The review confirms that STEAM approaches are particularly effective in engaging students who are traditionally underrepresented in STEM, including girls, students from disadvantaged backgrounds, and those with diverse learning profiles. By integrating the Arts and emphasizing hands-on, meaningful learning, STEAM creates inclusive entry points into technology and engineering. These findings carry significant implications for promoting equity in education and workforce development, especially in light of persistent gender and socioeconomic gaps in STEM fields.

4.3. The Role of the Arts: From Accessory to Epistemology

A key insight from the literature is that the Arts must be treated not as an accessory to STEM, but as a legitimate epistemological partner. When the Arts are fully integrated, they enrich learning by fostering critical reflection, emotional engagement, and cultural relevance. However, this requires a shift in mindset among educators, curriculum designers, and policymakers—one that recognizes artistic processes as central to knowledge creation, not merely tools for communication or motivation.

4.4. Implementation Requires Systemic Support

The success of STEAM education depends on **institutional and systemic conditions**. Isolated efforts by enthusiastic teachers are not enough. Sustainable implementation requires:

- Leadership support at the school and district levels;
- Ongoing professional development;
- Access to resources and flexible learning environments;
- Curricular frameworks that allow for interdisciplinary exploration.

Without these supports, STEAM risks becoming a short-term initiative rather than a lasting educational transformation.

4.5. Gaps in Research and the Quebec Context

While international research on STEAM is growing, there is a notable lack of empirical studies in the Quebec context. This limit constraint our understanding of how STEAM principles align with local curricula, teacher training programs, and cultural values. Future research should explore how STEAM can be adapted to Quebec's educational landscape, particularly in French-language schools and Indigenous communities' schools.

5. CONCLUSION

This narrative literature review has explored the multifaceted impact of STEAM education on youth attitudes toward technology. The integration of Science, Technology, Engineering, Arts, and Mathematics offers a powerful framework for reimagining education in ways that are more inclusive, engaging, and aligned with the demands of the 21st century. By fostering creativity, critical thinking, and interdisciplinary collaboration, STEAM not only enhances academic outcomes but also cultivates a more confident and positive relationship with technology among students.

The review highlights that, when implemented thoughtfully, STEAM education can reduce gender disparities, accommodate diverse learning profiles, and inspire students to pursue careers in science and technology. However, the success of STEAM depends on several key factors: conceptual clarity, authentic integration of the Arts, systemic support for educators, and alignment with real-world challenges.

Despite its promise, STEAM remains underdeveloped in certain regions, including Quebec, where further research and policy development are needed to support its integration into formal curricula. Future studies should focus on longitudinal impacts, culturally responsive practices, and scalable models of implementation.

In conclusion, STEAM is more than an educational trend—it is a transformative approach that prepares young people to navigate and shape a complex, technology-driven world. Continued investment in STEAM education is essential for building a generation of learners who are not only technically skilled but also imaginative, empathetic, and equipped to solve the pressing problems of our time.

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Annex A.

Studies retained & dimensions treated

	Authors	Year	Attitudes towards technology	Attitudes towards science	Social skills	Attitudes towards the arts	Creativity enhancement	Critical thinking	Problem resolution	Classroom implementation
1	Aguilera & Ortiz-Revilla	2021	False	False	True	False	True	True	True	True
2	Arango-Caro et al.	2025	True	True	True	False	True	True	True	True
3	Banate & Bauyot	2025	False	False	False	False	False	True	True	False
4	Bevan et al.	2020	True	True	False	False	False	False	False	True
5	Boice et al.	2024	True	False	False	True	False	False	False	True
6	Chang & Kidman	2025	False	False	False	False	False	False	False	True
7	Chappell et al.	2025	False	True	True	False	True	False	True	True
8	Chujitarom & Piriyasurawong	2018	True	False	False	False	True	False	True	True
9	Chung & Li	2021	False	True	True	False	False	True	True	True
10	Costantino	2018	False	True	True	True	True	True	True	False
11	Dell'Erba	2019	False	False	False	False	False	True	True	True
12	Dhanapal et al.	2014	False	True	True	True	True	True	True	True
13	Erawan et al.	2025	True	True	True	True	True	True	True	True
14	García-Llamas et al.	2025	True	False	True	False	True	True	True	False
15	Gess & Kuo	2019	False	True	True	True	True	True	True	True
16	Graham	2020	True	True	False	False	True	True	True	True
17	Herro et al.	2017	False	True	False	False	False	False	True	True
18	Hunter-Doniger	2021	False	False	False	True	False	False	True	True
19	Jantakun et al.	2021	False	False	True	True	True	False	True	True

20	Kijima & Sun	2021	True	True	True	True	True	True	False	True
21	Laksmiwati et al.	2018	True	False	False	True	False	True	False	True
22	Leavy et al.	2023	True	True	False	False	True	True	True	True
23	Li & Chung	2025	True	True	False	True	True	True	True	True
24	Liliawati et al.	2018	True	True	True	True	True	True	True	True
25	Lin & Chang	2025	True	False	False	True	True	True	True	True
26	McDaniel	2025	False	False	False	False	True	False	True	True
27	Mejias et al.	2021	False	False	True	False	True	True	True	True
28	Ozkan & Umdu Topsakal	2021	False	False	False	False	True	False	False	True
29	Perignat & Katz-Buonincontro	2019	False	False	False	False	True	False	True	True
30	Portillo-Blanco et al.	2024	True	True	True	True	True	True	True	True
31	Portillo-Blanco et al.	2025	True	True	True	True	True	True	True	True
32	Psycharis	2018	True	True	False	False	False	False	True	True
33	Quigley & Herro	2016	True	True	True	True	True	True	True	True

34	Sanz-Camarero et al.	2023	True	True	True	True	True	True	True	True
35	Sochacka et al.	2016	True	True	True	True	True	True	True	True
36	Spuzic et al.	2016	False	False	False	True	True	True	True	False
37	Tang et al.	2025	True	True	True	True	True	True	True	True
38	Vartiainen	2021	True	True	True	True	True	True	True	True
39	Velarde-Camaqui et al.	2024	True	True	True	True	True	True	True	True
40	Veziroglu-Celik et al.	2025	True	True	True	True	True	True	True	True
41	Wahyuningsih et al.	2020	True	True	True	True	True	True	True	True
42	Wang & Lin	2025	True	True	True	True	True	True	True	True
43	Wilson et al.	2021	True	True	False	True	True	True	True	True
44	Wu et al.	2021	False	False	False	False	False	False	True	True
45	Yim et al.	2024	True	True	True	True	True	True	True	True

PATT42: The 42nd International Pupils' Attitudes Towards Technology Research Conference

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From Sketch to Prototype: A STEAM-Based 3D Modeling Project in Elementary Geometry and Design

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Abstract

This paper presents a design-based research project conducted in two Grade 5 classes in rural Québec, where students engaged in a 3D modeling and printing activity titled *Bottle Your Creativity!* The activity aimed to foster design thinking, problem-solving, and computational thinking within a transdisciplinary STEAM framework. Students were tasked with designing and modeling personalized bottle prototypes using Tinkercad, while navigating mathematical constraints (volume, geometric solids), scientific reasoning (materials, environmental impact), and aesthetic considerations. Through classroom observations, student sketches, digital models, and interviews, the analysis reveals how learners iteratively engaged in creative and technical thinking, negotiated design constraints, and developed transferable computational strategies. Findings illustrate that integrating digital fabrication into elementary education can deepen conceptual understanding in geometry and measurement, while promoting learner autonomy, inclusion, and authentic connections across disciplines. The study offers a replicable model for STEAM-based pedagogical integration within the Québec curriculum and contributes to discussions on how making and modeling can support equity, creativity, and engagement in mathematics and science education.

Keywords: *STEAM education, 3D modeling and printing, project-based learning, elementary mathematics education, problem solving*

1. INTRODUCTION

The integration of 3D printing (3DP) in elementary education is increasingly recognized as a catalyst for active, interdisciplinary learning within the STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework. As Ng, Tsui, and Yuen (2022) observe, 3DP activities foster not only hands-on engagement with spatial reasoning but also stimulate computational and abstract thinking. Building on constructionist approaches (Papert & Harel, 1991), our research contributes to this movement by implementing design-based learning scenarios that blend mathematics and technology through tangible creation.

This paper presents and discusses the end phase of the first year of the two years research project (for now) on 3D modeling and printing in geometry education, focusing on the activity *Bottle Your Creativity!*, conducted in April-May 2025. Two Grade 5 classes in rural Québec were tasked with designing and prototyping bottles using computer-aided design tools. Compared to a previous keychain design activity (Mai Huy & Ouellette, 2025), this iteration involved more complex constraints: a targeted virtual volume, inclusion of cavities, functional caps, and proportional scaling.

The significance of this approach lies in its alignment with transdisciplinary STEAM learning, which encourages the blending of disciplinary knowledge into a cohesive, real-world inquiry process. As emphasized by Wilson et al. (2021), transdisciplinary designs elevate creativity and problem-solving by engaging students in authentic tasks that require the integration of multiple content areas. In the bottle design activity, learners had to mobilize a range of competencies—mathematical reasoning (e.g., spatial visualization, volume estimation and calculation, proportional scaling), scientific inquiry (e.g., understanding of materials, gravity, and structural balance), and artistic sensibility and design skills (e.g., aesthetics, branding, user interaction). This mirrors the principles outlined by Costantino (2018), who argues that transdisciplinary approaches enable students to synthesize and transfer knowledge across domains, fostering deeper cognitive engagement.

Recent research further supports the view that STEAM activities—when intentionally designed—can strengthen both conceptual understanding and metacognitive strategies. For instance, Filipe et al. (2024) demonstrate how integrated STEAM curricula enhance students' creativity and reflective thinking, particularly when design challenges are embedded within real-world simulations. Similarly, Kohen (2025) proposes a model for integrating structured mathematical modeling into design-based contexts, emphasizing the relevance of scaffolding abstraction and estimation when students engage with volume or capacity constraints—key dimensions of our own activity. In line with these findings, Bočková and Rumanová (2024) argue that contextualized modeling activities—particularly when situated outside traditional classroom environments—foster students' exploration of geometric properties and enhance engagement, especially in primary education.

Moreover, research by Henriksen et al. (2017) shows that engaging students in artistic design tasks within a STEAM framework contributes significantly to their creative confidence and willingness to experiment, essential skills for future problem-solvers. This convergence of artistic creativity with technical precision is further echoed by Vasquez et al. (2013), who advocate for integrated STE(A)M units that include open-ended design challenges, arguing they enhance both mathematical reasoning and collaborative learning dynamics.

In this light, our *Bottle Your Creativity!* activity not only reflects the values of integrated STEAM education but also serves as a prevailing platform to cultivate essential 21st-century skills such as abstraction, iterative design, reflective judgment, and collaboration. By actively bridging traditionally separated domains, students were invited to think as engineers, designers, and mathematicians simultaneously, thus experiencing a fuller, more meaningful approach to learning. Furthermore, by emphasizing inquiry-based learning and autonomy, this activity resonates with early STEAM learning principles (Harris & de Bruin, 2017; DeJarnette, 2018). Students were not only builders but also decision-makers, simulating entrepreneurial roles. As Perignat and Katz-Buonincontro (2019) underline, when art and design are deeply integrated—not merely added on—they foster a more genuine engagement with innovation. Through iterative design and collaboration, students engaged in processes of refinement that exemplify "thinking through making" (Bevan, 2017).

The activity also contributes to equitable access to digital making. As Roy, Caron, and Plante (2023) argue, meaningful technology integration in public schools helps reduce barriers to creative expression and technical literacy. The rural setting of this study offers an important context to demonstrate how 3DP can democratize access to modern tools for learning, thereby advancing the mission of STEAM education.

Moreover, the growing interest in 3D modeling and printing in education reflects a broader shift toward more interactive approaches to mathematical learning. Research by Cochran et al. (2016), Ndiaye et al. (2016), Ng et al. (2022), and Roy et al. (2023) demonstrates that 3D technologies can deepen student engagement with core concepts such as spatial reasoning and proportionality. Complementary French-language studies have shown that 3DP facilitates reasoning transitions between 2D and 3D geometry, enhances proportional thinking, and fosters spatial visualization (Beauset et al., 2024; Heitz Ferrand & Gillot, 2018; Nicod & Parisod, 2018). These tools also provide tangible, hands-on learning experiences that make abstract ideas accessible and concrete for young learners.

Lastly, the creative and collaborative dimensions of 3D modeling, highlighted by Ndiaye et al. (2016) and Heitz Ferrand & Gillot (2018), help foster motivation and peer learning. However, the integration of 3DP into geometry instruction also raises several didactic and methodological challenges: How does 3DP influence elementary students' understanding of geometric concepts? What barriers exist in adopting this technology among teachers and students? And how can its implementation be optimized to support long-term and meaningful learning? The current research aims to explore these questions through a pedagogical and didactic experiment that centers on learning volume and spatial transformations through STEAM-based, digitally fabricated design tasks.

2. METHODOLOGY

2.1. Research Design and Context

The study was conducted through a design-based research (DBR) methodology within a collaborative action-research framework (Desgagné et al., 2001; Somekh, 2006), which emphasizes iterative development, authentic learning contexts, and stakeholder collaboration. This methodological stance allowed the co-design and facilitation of learning activities by researchers, teachers, and technopedagogues. This approach was particularly well-suited for exploring the pedagogical impact of integrating 3D modeling and printing into elementary mathematics education through STEAM-based practices. The research involved a partnership between university researchers, primary school teachers, and a technopedagogue, allowing for continuous adjustment of the instructional design in response to classroom dynamics and student needs.

The iterative nature of the research was enacted through two implementation cycles: observations and informal feedback from the first classroom were used to refine the instructions, timing, and constraints before introducing the activity to the second group. These adjustments included clarifying the 100 mL volume target, reinforcing the importance of using at least three solids, and integrating explicit volume verification techniques using Tinkercad's measurement tools.

The study took place in two Grade 5 classrooms located in rural regions of Northern Québec. The participating students, aged 10–11, had previously been introduced to basic 3D modeling through a

preliminary activity focused on designing personalized keychains (Mai Huy & Ouellette, 2025). This earlier experience helped ensure a basic level of familiarity with Tinkercad[1] and digital fabrication workflows.

The main activity, titled *Bottle Your Creativity!*, unfolded over two 75-minute sessions per class and was structured into five pedagogical phases:
(1) contextualization and introduction of design and mathematical constraints;
(2) ideation and 2D sketching of bottle concepts;
(3) 3D modeling of a scaled bottle using Tinkercad;
(4) estimation of production and marketing costs using simplified economic criteria[2]; and
(5) fabrication of physical prototypes through 3D printing.

These phases were deliberately modeled on real-world design processes, mirroring cycles of ideation, prototyping, testing, and iteration common in both engineering and artistic design disciplines (Henriksen et al., 2019; Wilson et al., 2021). Moreover, the task encouraged students to navigate interconnected domains of mathematics, engineering, entrepreneurship, and the arts, aligning with integrated STEAM learning principles that prioritize transdisciplinarity, creativity, and learner agency (Kim & Park, 2023; Vasquez et al., 2013).

2.2. Pedagogical and Technical Constraints

The pedagogical design of the bottle activity included three main constraints to guide student learning and stimulate authentic decision-making. First, each design had to incorporate three to five geometric solids, including a detachable cap. This required students to engage with a variety of geometric forms (above all different forms and shape of prism from which the volumes of the designed solids can be calculated at Grade 5 level) and understand their volumetric implications. Second, students had to include at least one concave surface or internal cavity, a requirement that encouraged spatial reasoning and planning, particularly in relation to hollow structures and internal displacement. Third, the final 3D model had to reach a target virtual capacity of 100 mL, integrating proportional reasoning and unit conversions.

Beyond shape and volume, students were asked to simulate material choices among plastic, biodegradable PLA, metal, and aluminum—each carrying different environmental and economic trade-offs. This constraint introduced ethical and scientific reasoning, aligning with calls for sustainability education within STEAM frameworks (Becker & Park, 2011; Bower et al., 2020). Students also considered aesthetic appeal and user ergonomics, merging mathematical rigor with design sensibility.

Such cross-disciplinary constraints mirror real-world engineering and industrial design processes. As Liao (2016) notes, tasks that blend arts and sciences foster a kind of epistemic fluency, encouraging students to draw on diverse modes of reasoning. Moreover, these design challenges support what Yvain-Prébiski and

[1] Tinkercad is a free, browser-based 3D design and modeling tool developed by Autodesk. Widely used in educational settings, it enables students to engage in iterative design processes by manipulating geometric forms and spatial dimensions. Its accessibility and visual interface make it particularly suitable for fostering STEAM competencies — especially in mathematics, technology, engineering, and the arts — by supporting abstraction, spatial reasoning, and creative problem-solving through hands-on digital fabrication. See: https://www.tinkercad.com.

[2] This phase was part of the broader classroom project. The entrepreneurial extension was initiated and managed by the teachers and their students but was not formally documented within the scope of our research.

Discours (2022) describe as a pedagogy of STEAM by construction, where the act of making is deeply intertwined with conceptual understanding. Through this integrated framework, learners were not only solving a geometric problem but also constructing meaningful connections between abstraction, creativity, and physical reality.

2.3. Data Collection and Analysis

Data collection combined qualitative methods aligned with design-based research. Sources included detailed classroom observations, field notes, student worksheets, photographs of initial sketches, screenshots of students' evolving digital models, printed bottle prototypes, and semi-structured follow-up interviews with participating teachers and students (Paillé et Mucchielli, 2021). These data provided a holistic perspective on student engagement, learning processes, and the classroom dynamics surrounding the integration of digital fabrication tools.

Thematic analysis (Blumenfeld et al., 1991; Paillé et Mucchielli, 2021) was conducted to identify recurring patterns and divergences around three major analytical axes: (1) evidence of design thinking, such as iterative improvements, revisions, aesthetic evaluations, and empathy for imagined users; (2) problem-solving behaviors, including how students navigated design constraints, optimized proportions, or adjusted their models for printability; and (3) computational thinking and modeling practices (Herro, Quigley, Plank, Abimbade & Owens, 2022), including abstraction, decomposition, and the logical sequencing of geometric components during digital modeling in Tinkercad.

This three-part framework reflects current research advocating for transdisciplinary pedagogies that integrate the arts and sciences to nurture student agency and innovation (Costantino, 2018; Harris & de Bruin, 2017; Liao, 2016; Perignat & Katz-Buonincontro, 2019). As students iterated on their models, sometimes restarting from scratch or revising only specific parts, they illustrated what Bevan (2017) calls the productive "messiness" of making, where learning is non-linear, exploratory, and situated in authentic contexts.

Interview data underscored how teachers and their students perceived the activity as a rare opportunity to witness mathematical thinking emerge from creative practice. Students who were less confident in traditional math lessons appeared to thrive when given the chance to engage in tactile modeling and visual-spatial reasoning. These findings support research suggesting that STEAM practices contribute not only to academic learning but also to the development of cognitive flexibility, perseverance, and positive learner identities through hands-on construction (Henriksen et al., 2019; Ng et al., 2022; Roy et al., 2023).

2.4. Mathematical Modeling and 3D Design

Mathematical modeling, at the heart of mathematical activity, is a complex intellectual process used to represent, interpret, and solve real-world situations through mathematical tools. According to Yvain-Prébiski and Discours (2023), mathematical modeling not only helps give meaning to mathematical concepts but also allows the articulation of knowledge from various domains—reinforcing the inherently interdisciplinary nature of learning. In a school context, modeling involves students in an iterative process of problem identification, representation, analysis, and validation, enabling them to actively construct knowledge.

This vision aligns closely with our pedagogical and didactic approach, particularly through the integration of 3D modeling and printing. The use of a digital modeling environment such as Tinkercad transforms abstract geometric reasoning into tangible representations. By manipulating three-dimensional forms, students

translate mathematical constraints into visual and physical objects, deepening their understanding of measurement, proportion, and spatial transformations. The digital design environment thus acts as a mediating tool that extends mathematical thinking into action, supporting the construction of structured and critical reasoning.

As observed during the activity, this iterative model of exploration and feedback promoted meaningful engagement with core geometric concepts, which are often perceived as abstract or difficult by elementary-level learners. The fusion of 3D modeling and printing with mathematical reasoning created an authentic, embodied experience of problem-solving that aligns with both curriculum goals and the principles of STEAM education (Becker & Park, 2011; Ng et al., 2022; Kohen, 2025).

3. RESULTS AND PERSPECTIVES

The qualitative analysis of classroom interactions and team-based design dialogues offers substantial insights into the development of STEAM competencies through the bottle modeling activity. Guided by the thematic framework, design thinking, problem-solving, and computational thinking, three major patterns emerged from the data. These categories reflect not only students' cognitive engagement but also the social and procedural aspects of their learning. The activity fostered iterative reasoning, spatial abstraction, and collaborative troubleshooting, demonstrating how integrated, task-based experiences can cultivate key STEAM capacities such as creativity, adaptability, and self-directed learning within a digitally mediated environment.

3.1 Evidence of design thinking

Design thinking emerged as a central cognitive process during the activity, observable through iterative revisions, peer dialogue, and user-centered design decisions. Students frequently returned to their initial sketches, testing out different shapes and measurements in Tinkercad. This iterative design process, characterized by prototyping and refinement, reflects the cyclic stages of empathizing, ideating, prototyping, and testing central to design thinking (Brown, 2008). For instance, one team of students noted, "The height is 70 [mm]... but now the shape is too big," and proceeded to adjust dimensions several times before achieving a satisfying form. These iterations revealed not only concern for technical correctness but also aesthetic appeal and imagined user comfort.

Students demonstrated iterative design behaviors and aesthetic judgment during the creation process. One student explained: "I started by calculating everything on the sheet... then I used Tinkercad because I'm good with 3D tools. I also use Roblox Studio 3D at home" (student01). This reflects a transfer of digital competencies from informal settings to the classroom, supporting student agency in design. Another student noted an aesthetic reflection: "I made it like a juice bottle that I like" (student01), emphasizing the personal and aesthetic dimension of their design.

Misinterpretations of constraints also triggered critical thinking and revision: "I thought we were allowed to not have a cap... I had calculated it separately" (student02). This moment highlights how an initial misunderstanding became a productive entry point into deeper design engagement. Rather than abandoning the task or treating the cap as an isolated element, the student demonstrated initiative in calculating it independently, revealing early problem decomposition. When the discrepancy was noticed, the student revised their model, illustrating an important aspect of design thinking: constraint negotiation. This iterative process not only strengthened the technical outcome but also promoted metacognitive awareness. It reflects

how authentic, constraint-based tasks help learners to reframe problems, test assumptions, and adjust strategies—skills that lie at the core of design-driven learning environments.

Another explained, “We had to change the top part… it didn’t look good or hold the liquid right” (student04), showing iterative redesign based on both function and form. This adjustment demonstrates students’ ability to assess the aesthetic and practical viability of their prototype, and to modify their model accordingly—a hallmark of design thinking. Rather than adhering rigidly to an initial concept, students displayed flexibility and responsiveness to emergent flaws, treating these not as failures but as opportunities for improvement. This process reflects an authentic design cycle where feedback (visual, functional, or peer-based) informs and shapes the final product.

Classroom dialogue further illustrated emotional investment and user-centered thinking: “We wanted to make it beautiful, but also ergonomic for kids” (student04). This comment reveals a thoughtful engagement with the needs of potential users, blending aesthetic values with functional usability. It also indicates an early form of empathetic design, where students consider how their creation might be experienced by others—a cognitive and affective leap beyond self-referential design. By prioritizing both esthetics and ergonomics, learners embraced the dual goals of STEAM: to create with purpose and to think across disciplines. This fusion of imagination and analysis aligns with what Bevan (2017) and Henriksen et al. (2017) identify as essential to authentic design engagement: creating not just something that works, but something that matters. Through such reflections, students began to internalize design as a human-centered, iterative, and value-driven process.

Further, students articulated the importance of user needs and aesthetics: “It’s too straight, it has to look nicer... maybe we could change the shape of the bottom” (student04). This concern for both functional and visual design suggests that students were developing sensitivity to user experience—a hallmark of authentic design thinking. Additionally, moments of negotiation between teammates—such as “I refuse. This is a team project” or “No, this one will be mine”—indicated ownership and emotional investment in the design process. This aligns with the notion of “design identity”, where students begin to see themselves as capable creators and decision-makers (Bevan, 2017).

Teachers noted increased motivation in students who typically disengaged from math lessons. The emphasis on visual, tactile, and creative modalities allowed diverse learners to express understanding in nontraditional ways, reinforcing how design thinking in STEAM can serve as an inclusive pedagogical entry point (Henriksen et al., 2017).

3.2. Evidence of complex problem-solving

Throughout the activity, students confronted and navigated technical, mathematical, and collaborative challenges, often demonstrating flexible thinking and persistence. Several teams encountered difficulties when translating 2D sketches into accurate 3D representations. A revealing comment—“This is not it at all... it’s actually really ugly”—led to the collective decision, “Let’s start over.” This voluntary willingness to iterate demonstrates resilience, a hallmark of effective problem-solvers (Blumenfeld et al., 1991). Errors were not viewed as failure but as part of a natural trial-and-error process supported by team feedback and visual verification (Brown, 2008, Hendriksen et al., 2017).

Problem-solving behaviors emerged as students navigated geometric requirements and volume estimations. A student described: “I noticed the bottle had stretched on Tinkercad... I think the scale changed from

millimeters to milliliters" (student02). This awareness of technical error illustrates metacognitive monitoring, where the student not only detects a discrepancy in the model but also hypothesizes a cause rooted in the misinterpretation of measurement units. This kind of diagnostic thinking demonstrates an important shift from surface-level manipulation to reflective analysis, as students begin to connect their actions within the digital environment to concrete mathematical consequences. Recognizing that the object had "stretched" points to an emerging understanding of proportionality, scaling, and spatial consistency in modeling.

Another student remarked: "I adjusted the diameter because the hole was too small to fit the pencil" (student01), evidencing adaptive decision-making in response to real-world functionality. This example shows how students linked their virtual models to tangible needs, engaging in practical reasoning that blends mathematics, design, and usability. Rather than discarding the flawed model, the student chose to revise specific parameters, demonstrating perseverance and strategic refinement. This hands-on approach to problem-solving not only supports geometry learning but also cultivates agency and confidence. Together, these responses exemplify the iterative nature of STEAM learning, where troubleshooting and correction are seen not as failure but as integral steps in the design and thinking process.

Figure 1. Collaborative 3D modeling of a bottle using two distinct prisms in Tinkercad.

Furthermore, students showed a capacity to propose verification strategies: "Now I'll use the real sheet measures... I will double-check everything next time" (student03), indicating reflective practice.

Students also tackled practical constraints, such as volume calculations, spatial reasoning, and alignment of shapes. One moment of confusion around the manipulation of radius, "why does changing the radius make it round?" (student02), gave rise to peer explanation and direct guidance, facilitating conceptual clarity. Another team reflected, "We had trouble making the hole, because we had to place it just right... otherwise it would go all the way through" (student04), highlighting their awareness of spatial relationships and tolerance adjustments.

Peer collaboration also emerged as a problem-solving catalyst: "I helped her because she was stuck. She couldn't remove a shape, so I showed her the 'group' and 'ungroup' buttons" (student05). This illustrates how collaborative environments encourage reciprocal teaching and mutual support, key to STEAM classroom dynamics.

Such moments underscore how collaborative dialogue can mediate complex ideas and support the co-construction of knowledge (Harris & de Bruin, 2017). Moreover, teamwork introduced social problem-solving: deciding who modeled the cap, which material was most eco-friendly, and how to balance aesthetics with cost. These negotiations fostered not just task completion but also critical communication and empathy, key 21st-century competencies. The integration of artistic freedom with real-world constraints created a rich space for authentic problem-solving experiences.

3.3. Computational thinking and modeling

Students displayed numerous behaviors linked to computational thinking (Herro et al., 2022), particularly in terms of abstraction, sequencing, decomposition, and debugging. As they manipulated parameters such as height, width, and wall thickness in Tinkercad, they gradually learned to conceptualize abstract numeric values as spatial features. One student verbalized: "This is 50 [mm]... the height is 70 [mm]," revealing how learners interpreted numeric measurements in a visual and interactive modeling environment. These forms of spatial-numerical reasoning exemplify how digital modeling can externalize and reinforce internal computational processes (Ng et al., 2022).

Several participants reported developing their modeling in logical steps. "We added the measurements, placed the base, then added shapes one by one" (student01), shared one student, demonstrating not only sequencing but also an emerging sense of procedural order. Another described their creative routine: "We did the base first, then the middle, then we resized the top because it didn't match our sketch" (student02). These accounts reveal how students combined geometric reasoning with a computational workflow, iterating between planning and execution. Rather than randomly assembling shapes, they engaged in deliberate sequencing, testing, and refining, mirroring real-world design and coding processes. This reinforces the educational value of 3D modeling platforms like Tinkercad in supporting structured, logic-driven problem solving.

Tinkercad served as a dynamic space where students transformed sketches into concrete 3D models. One student noted, "I imagined the shape in 3D when I was sketching… but Tinkercad helped me see the real dimensions" (student01), illustrating the shift from abstract to spatial reasoning. This transition is essential in both mathematics and computational thinking, as learners begin to visualize and manipulate forms in a dimensional context. Another explained: "We added the shape, then rotated it, then shrank it, and added another shape" (student03), demonstrating intuitive algorithmic thinking through step-by-step transformations. These actions reflect core computational skills such as sequencing and iteration, naturally embedded in the modeling process (Herro et al., 2022). By allowing real-time adjustments and experimentation, Tinkercad supported both geometric understanding and the development of logical, procedural reasoning.

Debugging was another critical dimension of computational engagement. Students often confronted design errors and addressed them with iterative strategies. One participant noted: "Our shape wasn't printing... so we had to redo the whole base to make it stand…" (student05). Another stated: "Our bottle had holes. So, I had to group everything again and check the alignments" (student006), demonstrating awareness of virtual construction logic and the procedural actions necessary to correct misalignments. These moments reflect not only technical awareness but cognitive flexibility, hallmarks of computational literacy.

Moreover, students exhibited early signs of algorithmic decomposition and strategic planning. One student summarized their process as: "I had to think of it like code… first this shape, then that one, then rotate it so it

fits" (student07). This insight reinforces the idea that even in elementary settings, design tasks embedded in digital tools can foster key computing concepts such as sequencing, control flow, and optimization.

Taken together, these findings confirm that digital modeling environments like Tinkercad can serve as prevailing platforms for cultivating computational thinking (Herro et al., 2022). They help make abstract mathematical and logical structures visible and manipulable, promoting cognitive processes that are foundational for future engagement in science, technology, engineering, and mathematics.

3.4. Toward a tangible, situated STEAM experience

The 3D bottle modeling activity transcended its surface-level technical goals by immersing students in a meaningful, collaborative, and transdisciplinary STEAM learning experience. Far from being limited to a single subject area, the activity combined geometry, material science, economics, artistic design, and digital modeling, mirroring real-world product development cycles. The process allowed students to engage cognitively, socially, and emotionally, bridging abstract concepts with embodied practice. This aligns with the "STEAM by construction" approach (Yvain-Prébiski & Discours, 2022), which promotes learning through making as a way of integrating domains.

The situated nature of the activity was further amplified by its local relevance and the students' ability to imagine real users of their bottles. As one student said, "If it's a bottle for children, it shouldn't break easily" (student03). Teachers observed that even students who tend to struggle usually in abstract reasoning tasks became highly engaged when working with 3D modeling and physical representations. These observations echo research by Wilson et al. (2021) and Harris & de Bruin (2017), emphasizing how inclusive and multisensory STEAM environments foster broader participation and deeper understanding.

STEAM integration was evident across disciplines. Students navigated geometry and volume, made aesthetic choices, and discussed real-world applications. One student stated: "This helps for measurements and building houses... my brother wants to be an architect" (student02), demonstrating future-oriented thinking and connections to engineering roles. Another recognized the importance of integrating 3D into the curriculum: "I'd like if our teacher used more Tinkercad in math… it helps with geometry" (student03). These testimonies align with the call for authentic, interdisciplinary experiences in STEAM education.

Moreover, students expressed clear evolution in their confidence and skill: "At first, I didn't use Tinkercad much. Now, I'm more used to it" (student02). This shift highlights how sustained exposure to STEAM activities nurtures not only skill acquisition but also identity formation as makers and problem solvers. Also, Teachers observed heightened engagement from students who typically struggled in abstract math contexts: "Normally he doesn't participate, but here, with the computer and drawing... he was leading the team" (teacher01).This supports research showing how inclusive, multimodal STEAM environments increase participation and identity formation (Wilson et al., 2021). While the activity offered many benefits, some challenges emerged. Not all students were equally comfortable with 3D software navigation, and time constraints limited opportunities for deeper iteration or peer review. In future implementations, longer project timelines and scaffolded digital modeling tutorials could increase accessibility and impact.

Teachers also expressed the need for ongoing professional development to confidently integrate digital modeling into regular curriculum. The novelty of the tool created excitement but also revealed gaps in both teacher training and curriculum alignment.

Moreover, the collaborative atmosphere created space for dialogic learning, peer teaching, and joint decision-making. As students debated materials, costs, and aesthetics, they were not just learning content, they were becoming collaborative designers and critical thinkers. Future iterations could deepen this engagement by incorporating user testing or sustainability assessments, linking STEAM to citizenship and ethical innovation.

4. CONCLUSION

The *Bottle Your Creativity!* activity, situated within a rural and digitally constrained educational context, strongly demonstrates the potential of integrated STEAM learning to cultivate students' design thinking, problem-solving, and computational thinking competencies. As evidenced throughout the study, students were not only capable of navigating complex constraints in 3D design and modeling but also demonstrated notable autonomy, creativity, and collaborative engagement. The iterative and tangible nature of the design process fostered sustained attention, and a sense of ownership rarely observed in more traditional math instruction.

Design thinking emerged through students' empathic considerations for the end-user and their willingness to revise and refine prototypes. Problem-solving was seen in students' capacity to confront challenges: technical, mathematical, or social, and adapt their strategies accordingly (Perignat & Katz-Buonincontro, 2019). Computational thinking was present in the procedural decomposition of modeling steps, alignment of shapes, and iterative debugging. Most significantly, the activity provided an integrated STEAM experience: students simultaneously engaged cognitive, affective, and social dimensions while navigating disciplinary boundaries between mathematics, art, science, and technology.

These findings reinforce the importance of authentic, construction-based pedagogies in elementary education. The project affirms that when students are placed in creative roles — engineers, designers, entrepreneurs — they do not merely consume knowledge but construct it meaningfully (Becker & Park. 2011). Furthermore, the rural setting of the study exemplifies how equitable access to digital tools can be a lever for empowerment and inclusion.

Finally, this research aligns closely with several elements of the Québec education program (PFEQ), particularly in mathematics (geometry and measurement), science and technology (material properties, environmental impact), and the development of cross-curricular competencies such as problem-solving, using information and communication technologies, and creative thinking. It also resonates with elements from other subject areas such as the Arts and Ethics and Religious Culture, particularly through the development of critical judgment, aesthetic awareness, and reflection on human-environment interactions. For example, students' reflection on form and function, as well as the environmental implications of material choices, show how 3D modeling can foster a multidisciplinary perspective and encourage ethical and artistic reasoning.

The STEAM activity described here provides a concrete and engaging way to operationalize these competencies, supporting the call for more authentic, interdisciplinary experiences in school. With the increasing availability of 3D modeling tools in education, this study offers a replicable model for integrating maker-based pedagogy within existing curricular structures. These findings contribute to the growing body of literature advocating for design-based and maker-centered learning environments as catalysts for integrated STEAM development in elementary education worldwide. Unlike other STEAM activities such as robotics or coding, 3D modeling uniquely supports spatial reasoning, geometric abstraction, and tangible engagement

with concepts like volume, surface, and structure. Its visual and manipulative nature also makes it highly inclusive for learners with diverse cognitive profiles, offering concrete representations that bridge abstract mathematical thinking with hands-on design.

Future research should continue to investigate how such interdisciplinary activities can be scaled and adapted across diverse educational contexts (Harris & de Bruin, 2017). However, future implementations should consider potential logistical challenges, such as teacher training in 3D modeling tools and access to reliable printing equipment. Particular attention should be paid to teacher support and training, ensuring that pedagogical strategies are in place to sustain student agency while deepening disciplinary learning. By continuing to explore the educational affordances of digital making and 3D modeling, we can move closer to a truly integrated, equitable, and transformative STEAM pedagogy.

5. LIMITATIONS

This study presents certain limitations that must be acknowledged. First, one of the two participating teachers were already engaged in pedagogical innovation and showed a strong interest in STEAM education and digital tools such as Tinkercad. His motivation and openness to experimentation influenced both the quality of implementation and the student engagement observed and may not reflect the conditions found in all primary classrooms, particularly those less resourced or with less teacher support. Second, the research was conducted in two rural Québec schools with relatively homogeneous student populations. As such, findings may not be fully generalized to more urban or culturally diverse educational settings. Furthermore, the study focused on a specific and bounded activity, the modeling and printing of a 3D bottle, which, while rich in learning potential, represents only one instance of STEAM integration. A broader longitudinal approach involving varied tasks and multiple cycles would provide deeper insight into students' progression and the transferability of competencies. Finally, data were primarily collected through observations, interviews, and student work artifacts; future studies could benefit from triangulating these with quantitative learning outcomes or teacher-reported assessment data to better capture the impact on academic achievement.

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The Intersection of Policy, Research, and Technology, Engineering and/or Design Education: A Systematic Search and Review

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ABSTRACT

This study explores the intersection of policy, research, and practice in technology, engineering and/or design education through a systematic search and review. The research aims to examine how empirical findings influence curriculum policymaking and identify evidence-based strategies for advancing TED education globally. Guided by PRISMA protocols, the review utilised Scopus as the primary database, applying rigorous inclusion criteria to select empirical studies published between 2015 and 2025. Data extraction and thematic synthesis were conducted collaboratively using human-led analysis supported by generative AI tools. Findings reveal a complex, non-linear relationship between research and policy, characterised by mutual shaping rather than direct causation. Key themes include evolving research trends toward integrated STEM and design-based learning, policy responses embedding engineering design into national frameworks, and the transformative role of digital technologies such as CAD and robotics. However, persistent challenges mediate the translation of research into practice, such as equity in technology access, curriculum overload, and limited teacher agency. The review underscores the need for policies that actively involve educators, provide sustained professional development, and address systemic inequities. It also highlights gaps in subject-specific policy research, calling for broader, more inclusive studies and cross-sector collaboration. These insights inform future research agendas and policy development aimed at fostering equitable, research-informed TED education policy.

Keywords: *curriculum, policy, research, sustainability, technology education, systematic search and review, TED education.*

1. INTRODUCTION

The convergence of educational policy, research methodologies, and technological innovation has transformed modern engineering and design education, creating complex interactions that warrant systematic examination. This comprehensive review investigates the dynamic relationships between policy frameworks, research practices, and technological integration in engineering and design education, with particular focus on identifying evidence-based approaches

for educational advancement. This paper presents the emerging findings from a systematic literature review exploring the intersections between policy and research in technology, engineering and/or design (TED) education subjects around the world.

2. METHODOLOGY

This paper is a systematic search and review, that followed a structured protocol based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was undertaken as a pilot to rapidly sample potential literature and trial the protocol in advance of a more thorough study. The review process encompassed several key stages to maintain rigour and transparency in the analysis, and utilised human-led collaboration with generative artificial intelligence (Gen-AI).

2.1 Search Strategy and Database Selection

Scopus was selected as the sole database for this systematic literature review because it offers broad multidisciplinary coverage, indexing high-quality, peer-reviewed sources under strict inclusion standards. Its advanced search and filtering tools support transparent and reproducible methods, while integrated citation metrics help identify influential studies. Using a single, comprehensive database ensures consistency and keeps the review manageable within the scope and constraints of a conference paper, aligning with accepted systematic review practices when justified by objectives and resources. The search terms combined key concepts related to policy, research, and technology/engineering/design education using Boolean operators. The initial search parameters were limited to peer-reviewed articles published between 2015-2025 in English-language journals. The search strategy was refined through iterative refinement of keywords and inclusion of relevant synonyms to ensure comprehensive coverage of the research domain, leading to the search string in Figure 1. The search.

FIGURE 1. *Boolean Search String.*

```
( TITLE-ABS-KEY ( "design and technology" ) OR TITLE-ABS-KEY ( "technology
education" ) OR TITLE-ABS-KEY ( "engineering education" ) AND TITLE-ABS-
KEY ( research ) AND TITLE-ABS-KEY ( policy ) AND TITLE-ABS-
KEY ( school ) ) AND PUBYEAR > 2014 AND ( LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-
TO ( SUBJAREA , "ARTS" ) ) AND ( LIMIT-
TO ( DOCTYPE , "ar" ) ) AND ( EXCLUDE ( EXACTSRCTITLE , "British Journal Of Educational
Technology" ) ) AND ( LIMIT-TO ( SRCTYPE , "j" ) ) AND ( LIMIT-
TO ( LANGUAGE , "English" ) )
```

Related search terms such as or “craft education” or “sloyd” were not included, being relatively geographically limited in usage compared to those selected. However, the exclusion of the term “technologies education” may have excluded potentially relevant studies from the Oceana region. After earlier iterations of the search string, the search was also limited to English language, peer

reviewed journal articles in the social sciences and arts and humanities subject areas. The *British Journal of Educational Technology* was specifically excluded due to the articles retrieved related to educational technology (EdTech) as opposed to TED education subjects. The literature search on Scopus was conducted on 25/03/2025 using the search string, and elicited 19 articles, which were scrutinised against the research question (RQ) below and selection criteria in Section 2.2. *RQ: To what extent do research findings influence policymaking in school curricula for design and Technology Education?*

2.2 Selection Criteria

Studies were evaluated and selected on a best fit approach, with the authors independently rating the original sample, based on the criteria below:

- Empirical research studies (QUAN, QUAL, or MMR) that provide data related to students' knowledge, capabilities, and attitudes concerning engineering and technology.
- Studies that discuss the influence of research findings on the development or revision of educational policy or curriculum frameworks.
- Publications addressing the implementation of technology, engineering, or design curricula and the role of stakeholders, including teachers, in that process.
- Articles in peer-reviewed journals focusing on Science, Technology, Engineering and Mathematics (STEM) education or interdisciplinary fields where engineering and design are explicitly tied to science contexts.
- Studies available in English and accessible in full text.

Studies primarily focused on adult higher education, professional development without clear links to student outcomes, or those without empirical data on student learning were excluded.

2.3 Data Extraction and Analysis

A coding framework was developed to extract relevant data from the selected articles, initially using GenAI (Paperguide, 2025) to identify common themes across the selected article. Two independent reviewers assessed each article using a standardised data extraction form. The extracted information included: (a) research methodology and design; (b) policy context and framework; (c) key findings and recommendations; (d) theoretical underpinnings; and (e) geographic location and educational context

2.4 Quality Assessment

Each study underwent quality assessment using established criteria for educational research. This evaluation examined methodological rigour, clarity of research objectives, data analysis

procedures, and the validity of conclusions. Studies were rated on a quality scale, with those scoring below the threshold being excluded from the final analysis.

2.5 Synthesis of Findings

The analysis employed a thematic synthesis approach to identify recurring patterns and themes across the selected studies. This process involved coding the findings of primary studies and developing analytical themes that went beyond the original research. The synthesis focused on understanding how policy, research, and practice interact within TED education contexts.

2.6 Included Studies

The systematic review incorporated a diverse range of empirical studies that examine the integration of Technology, Engineering, and Design principles into school curricula and their influence on policy development. The selected articles span qualitative, quantitative, and mixed-methods research published from 2015 onwards, reflecting evolving trends and priorities in TED education research. TABLE 1 summarises key details of the included studies, highlighting their focus, methodology, and relevance to the research question.

TABLE 1. *Articles included*

Article	Study Focus	Methodology	Key Findings	Policy Relevance
Antink-Meyer et al. (2025)	Integration of engineering in science education	Qualitative systematic review	Identified challenges in teacher-centred approaches limiting genuine problem-solving	Highlights need for pedagogical shifts to support policy goals
Sneider & Ravel (2021)	STEM literacy and curriculum frameworks	Literature synthesis	Emphasised formalisation of engineering in K12 standards	Informed development of NGSS and related policies
Dai et al. (2022)	Teacher agency and cross-sector collaboration in curriculum change	Mixed methods case study	Showed importance of teacher professional growth and partnerships in policy enactment	Supports inclusive policy implementation strategies
Lane et al. (2022)	Problem-solving processes in design education	Qualitative analysis	Problem-solving described as social and iterative, often undermined by traditional methods	Calls for policy attention to pedagogical quality

The included articles were selected for their empirical focus on the integration of TED principles into school curricula and their explicit examination of how research influences educational policy and practice. They encompass diverse methodologies, providing comprehensive insights into pedagogical challenges, teacher agency, and policy enactment relevant to TED education. Conversely, 15 studies from the initial search were excluded where they lacked empirical data on student learning, focused solely on adult higher education or professional development without clear policy links, or did not address the interface between research and curriculum policy. This selection ensures a focused understanding of research-policy dynamics within K12 TED education contexts.

2.7 Analysis and Synthesis

Data extraction was conducted systematically wit, key information extracted from each included study, including the publication year, study design, research questions, participant demographics, educational context, key findings related to student learning and engagement, discussions of policy implications, and observed interactions between research, policy, and practice. Information regarding technological tools or pedagogical innovations was also recorded. The extraction process involved multiple reviewers to ensure consistency and reliability, with discrepancies resolved through discussion. Data synthesis employed a thematic analysis approach, which is particularly suitable for qualitative systematic reviews where the aim is to describe the landscape of research and identify recurring patterns. This involved an iterative process of coding extracted data, identifying emergent themes, and grouping these themes into broader categories. Specific attention was paid to how research questions were framed, the stakeholders involved, and the focus of the studies (e.g., student content learning, teacher pedagogy, attitudes, access). The synthesis sought to trace the flow of influence from research to policy and practice, identifying mediating factors and barriers. Quantitative aspects, such as the prevalence of certain research topics or the reported effect sizes of interventions where available, were integrated into the thematic narrative to provide empirical depth.

2.8 Quality Assessment and Limitations

The quality of included studies was assessed using established criteria relevant to their respective methodologies. For quantitative studies, attention was given to sample size, statistical rigor, and validity of measures. For qualitative studies, credibility, transferability, dependability, and confirmability were considered. Studies that did not provide clear methodologies or sufficient evidence to support their claims were noted for their limitations in contributing to robust conclusions. This approach allowed for an evaluation of the strength of evidence supporting the identified themes and conclusions. Despite careful adherence to systematic review protocols, inherent limitations exist. The review's scope was confined to English-language publications, potentially excluding relevant non-English research. The selection of journals, though based on impact and relevance to science education, might not fully capture all scholarship within the

broader engineering and technology education fields. Furthermore, grey literature, which can offer insights into policy development and implementation that do not appear in peer-reviewed journals, was not systematically included, potentially leading to publication bias. While the review identified trends, it does not definitively establish causation between specific research findings and direct policy changes, as policymaking is a complex process influenced by numerous factors beyond academic research

3. THEMATIC ANALYSIS

This thematic analysis presents a dynamic interplay between research, policy, and practice within TED education. Distinct themes emerged, highlighting evolving research trends, policy responses to empirical evidence, and the transformative impact of technological advancements on curricula.

3.1.1 Evolving Research Trends in Technology and Engineering Education

Research in Technology and Engineering Education has diversified considerably, reflecting a growing complexity in the field. Initial studies often focused on integrating engineering into science contexts, with a significant proportion examining student learning of science content through engineering experiences (Antink-Meyer et al., 2025). Teacher pedagogy and practice regarding engineering within science or vice versa also represented a prominent research focus (Antink-Meyer et al., 2025). More recent trends reflect a broadening scope, including exploration of learner agency, access to engineering and science, and critical examinations of STEM career pathways (Antink-Meyer et al., 2025). Dai et al. (2022) highlight evolving research trends in technology and engineering education by showcasing how artificial intelligence (AI) is being integrated into primary school curricula through teacher-led initiatives. It reflects a shift toward early exposure to emerging technologies, emphasising conceptual understanding, ethical awareness, and inclusive pedagogy. This underscores the growing importance of cross-sector collaboration (particularly between schools and universities) and the role of teacher agency in curriculum innovation. It also points to a broader epistemological shift, where engineering education is moving from content delivery to knowledge construction, aligning with lived experiences of learners in media-rich, technology-saturated environments.

3.1.2 Empirical Evidence on Pedagogical Innovations

Empirical evidence supports the efficacy of various pedagogical innovations in TED education. Studies demonstrate that fully integrating engineering into science lessons is more effective than using engineering activities as a mere capstone (Sneider & Ravel, 2021). A particularly effective approach involves providing students with a suboptimal design as a starting point, encouraging creative redesign and performance improvement through frequent testing and iteration (Sneider & Ravel, 2021). Visual and computational tools also contribute positively; teaching drawing explicitly, including paper-and-pencil sketching and Computer-Aided Design (CAD), has proven beneficial for developing design solutions and science-based decision-making skills (Sneider &

Ravel, 2021). For instance, a CAD unit for high school students resulted in significant learning gains ($p < 0.00015$, Cohen's $d = 0.954$) in science and engineering understanding (Sneider & Ravel, 2021). Problem-solving, a core tenet of TED subjects, has been a subject of extensive research regarding its pedagogical implementation. While often reduced to a ritualistic series of steps in classrooms, research advocates for approaches that foster genuine student thinking and decision-making (Lane et al., 2022). Initial teacher education (ITE) and professional development (PD) programmes aim to challenge teachers' conceptions of problem-solving, moving them towards more authentic and meaningful classroom practices (Lane et al., 2022). However, the impact of PD on teachers' deep reconceptualization of practice remains a challenge, as superficial adoption of new methods can occur without a full appreciation of the underlying rationale (Lane et al., 2022).

3.1.3 Emergent Themes in Interdisciplinary Approaches

Interdisciplinary approaches, particularly the integration of STEM components, represent a significant emergent theme. The focus has broadened from solely science-engineering connections to encompass a more holistic STEM integration (Sneider & Ravel, 2021). Research explores how engineering design promotes content knowledge across traditional subject domains, including literacy, in addition to engineering design practices, thinking, and professional skills (Antink-Meyer et al., 2025). The concept of *design-based learning* has gained traction as an alternative to traditional inquiry-based science education, centring the pedagogical utility of design (Antink-Meyer et al., 2025). This includes the exploration of how students engage in problem scoping through fictional stories and the use of real-world technological systems to spark interest and engagement (Sneider & Ravel, 2021). The application of integrated STEM curricula has also been evaluated for its effectiveness in specific learning outcomes, such as middle school students' life science learning (Antink-Meyer et al., 2025). Furthermore, there is a growing recognition of the importance of connecting learning to family and community contexts, moving beyond compartmentalised science and engineering knowledge (Antink-Meyer et al., 2025). This highlights a move towards understanding integrated learning within sociocultural underpinnings and promoting equity (Antink-Meyer et al., 2025).

3.2 Policy Responses to Research Evidence

Policy responses in TED education frequently reflect attempts to incorporate research findings, albeit with varying degrees of directness and success. The development of major educational frameworks, such as the Framework for K12 Science Education and the Next Generation Science Standards, was influenced by an increasing societal recognition of the need for STEM literacy, a concern often highlighted by educational research (Sneider & Ravel, 2021). These frameworks, in turn, have driven systemic change across US states, with 44 states adopting or adapting them (Sneider & Ravel, 2021). Dai et al. (2022) recommend that teachers should be involved in curriculum policymaking to ensure relevance and ownership, professional development should

include epistemological training and cross-sector collaboration, and curriculum design must consider students' diverse socioeconomic backgrounds and access to technology.

3.2.1 Integration of STEM and Design Thinking Frameworks

Policy documents explicitly promote the integration of STEM disciplines and design thinking. For example, the Framework for P12 Engineering Learning (FP12EL) and the Standards for Technology and Engineering Literacy provide learning goals that integrate concepts from the Next Generation Science Standards (NGSS) while also extending beyond them to provide a more robust engineering focus (Sneider & Ravel, 2021). These policy initiatives were developed through collaborative processes involving educators, researchers, and other stakeholders, seeking consensus on what students should learn about engineering (Sneider & Ravel, 2021). This indicates a direct pipeline from research-informed consensus to policy formulation. The emphasis on engineering design processes within these frameworks aligns with research advocating for design-based learning as a pedagogical utility (Antink-Meyer et al., 2025). Policies now encourage engaging students in problem-solving and iterative design, mirroring research findings on effective teaching methods (Sneider & Ravel, 2021). However, the extent to which these policy aspirations translate into actual classroom practice often depends on teachers' agency and their ability to interpret and implement these frameworks in their local contexts.

3.2.2 Regulatory Mechanisms and Curriculum Reform

Regulatory mechanisms and curriculum reforms, such as the introduction of engineering into official science education standards, represent direct policy responses to perceived educational needs and research findings (Antink-Meyer et al., 2025). These reforms aim to ensure improved access to engineering literacy for all students (Antink-Meyer et al., 2025). The incorporation of engineering education is often seen as a means to make science more relevant and to highlight the societal impacts of technology (Sneider & Ravel, 2021). Policy also addresses the professional development of teachers as a key regulatory mechanism for effective curriculum reform (Dai et al., 2022; Lane et al., 2022). Research indicates that teachers' involvement in policymaking processes can build trust and commitment to change, thereby sustaining curriculum reforms. Collaborative efforts, such as school-university partnerships, are identified as critical for enhancing teachers' professional capacity and teaching practices, directly supporting the regulatory goals of policy. Despite these efforts, curriculum overload and the focus on high-stakes summative assessments can hinder the full implementation of TED subjects, particularly when they are not centrally assessed.

3.3 Technological Advancements and Curricular Transformation

Technological advancements are a driving force behind curricular transformation in design and technology (D&T) education, necessitating ongoing adaptation to prepare students for future contexts. Research in this area frequently focuses on the integration of digital tools and addressing equity concerns related to access.

3.3.1 Digital Tools in Teaching and Learning

The integration of digital tools has substantially influenced teaching and learning in TED. Computer-aided design (CAD) platforms have been investigated for their ability to enhance science-based design decisions, showing significant learning gains for students (Sneider & Ravel, 2021). Educational robotics, a topic of significant research attention, also exemplifies the use of digital tools to engage students in engineering concepts (Sneider & Ravel, 2021). Studies on educational robotics have explored various aspects, including students' interest, self-efficacy, and the impact of different robot types (e.g., rigid vs. soft robots) on engagement (Sneider & Ravel, 2021). Digital fabrication tools, such as 3D printers, also change student perceptions of their role in the classroom by enabling hands-on design and creation (Sneider & Ravel, 2021). These tools facilitate more authentic design experiences, allowing students to engage in iterative processes of testing and refinement, mirroring professional engineering practices (Sneider & Ravel, 2021). The research on digital tools extends to exploring their use in specific thematic areas, such as designing biomedical devices or electrical alarm systems, offering diverse avenues for student engagement (Sneider & Ravel, 2021).

3.3.2 Equity, Access, and Technological Adoption

The adoption of new technologies in TED education raises critical questions regarding equity and access (Dai et al., 2022). Research highlights concern about the widening socioeconomic gap among students, particularly concerning differentiated access to digital devices, including high-tech or AI-powered gadgets. This disparity can lead to discrimination against socially and economically disadvantaged students, necessitating concerted efforts from both public and private sectors to foster inclusive learning opportunities. Studies also examine gender differences in engagement with technological systems. For example, while boys might prefer programming, girls often show greater interest in biomedical engineering (Sneider & Ravel, 2021). However, using materials like e-textiles, where girls may feel more comfortable, has been shown to enable them to take leadership roles in co-ed teams, suggesting that choice of technological system can mitigate gender disparities in areas like ‘tinkering self-efficacy’ (Sneider & Ravel, 2021, p.13). Research consistently points to the need for long-term support for students, particularly girls and those from low-income families, to maintain interest and pursue engineering as a profession (Sneider & Ravel, 2021). Addressing these equity concerns through research-informed policy and practice is fundamental to ensuring equitable access to TED education.

4. ANALYSIS AND SYNTHESIS OF FINDINGS

The synthesis of findings across the identified themes reveals a complex and often indirect relationship between research evidence and educational policymaking in TED education. While policy frameworks increasingly articulate goals aligned with research-backed pedagogies and content, the translation into widespread, equitable practice remains contingent on various mediating factors.

4.1 Patterns of Influence: From Research to Policy Implementation

A pattern of influence exists where research findings contribute to the conceptualisation and justification of new educational policies. The widespread adoption of integrated TED education, for instance, is a direct response to a societal need for STEM literacy, a need extensively documented by research (Sneider & Ravel, 2021). Policy documents, such as the NGSS and the FP12EL, reflect research-informed understandings of engineering design as a core competency (Antink-Meyer et al., 2025; Sneider & Ravel, 2021). These policies embed pedagogical recommendations, such as the utility of design-based learning, which are rooted in empirical studies (Antink-Meyer et al., 2025). However, the influence is rarely a linear, unidirectional flow. Instead, it is often a process of mutual shaping, where policy initiatives create demand for specific research, and research, in turn, provides the evidence base for refining or expanding those policies (Antink-Meyer et al., 2025). For example, the formal incorporation of engineering into science education standards has spurred a growing body of scholarship, which then illuminates challenges and opportunities that may inform future policy revisions (Antink-Meyer et al., 2025). Research also reveals gaps in policy, such as the discrepancy between calls for broad access to STEM education and research's continued focus on traditional settings (Antink-Meyer et al., 2025). Furthermore, there is a lack of robust research to inform TED subjects, like D&T in England, as opposed to STEM education, which tends to be focused more on science and mathematics. This suggests that while research provides a critical lens for policy, its full impact is contingent on reciprocal engagement and a willingness of policymakers to address critical insights.

4.2 Mediating Factors Affecting Research Uptake in Policymaking

Several factors mediate the extent to which research findings are taken up in policymaking:

Teacher Agency and Professional Development: Teachers are crucial mediators of policy into practice. Their strategic interpretation and harnessing of policies, often informed by professional development experiences, determine the fidelity and effectiveness of implementation. Research indicating that teachers can strategically interpret policies underscores the importance of involving them in policy design.

Cross-Sector Collaboration: Partnerships between schools, universities, and industry significantly enhance teachers' professional capacity and access to expertise, thereby facilitating the adoption of research-informed practices. These collaborations serve as vital channels for knowledge transfer, allowing research to influence practice more directly.

Assessment and Curriculum Prioritisation: The emphasis on high-stakes summative assessments can inadvertently marginalise TED subjects if they are not part of core assessment requirements. This can lead to curriculum overload and competition for limited teaching time, hindering the full implementation of research-backed reforms.

Technological Infrastructure and Equity: The effectiveness of integrating digital tools and advanced technologies depends heavily on equitable access to resources. Policies must address the socioeconomic disparities in technology access, as highlighted by research, to avoid exacerbating educational inequalities.

Disciplinary Hegemony and Critical Perspectives: Research critiques the potential for policy to reproduce disciplinary hegemonies, questioning whether the integration of engineering within science education adequately challenges existing power structures or merely perpetuates them. This critical perspective, if acknowledged by policymakers, can lead to more nuanced and equitable policy designs.

In essence, while research provides the foundational evidence, its influence on policymaking is profoundly shaped by the contextual realities of educational systems, including the capacity of educators, the availability of resources, and the broader socio-cultural environment.

5. DISCUSSION

The preceding analysis underscores the complex interplay between research, policy, and practice in TED education. While a clear movement towards integrating engineering and technology into curricula is evident, driven by both societal demands and research findings, the process is far from seamless. Understanding the implications for stakeholders and acknowledging persistent challenges and opportunities are central to fostering policy-informed practice.

5.1 Implications for Stakeholders in Design and Technology Education

The findings carry significant implications for various stakeholders involved in TED education:

Policymakers: It is important for policymakers to acknowledge the iterative nature of research-policy interaction. Policies benefit from being evidence-informed, yet their design must also consider the practical realities of implementation. Policies should not merely mandate new content but also support the necessary teacher professional development and resource allocation to ensure effective translation of research-backed pedagogies into classrooms.

Researchers: The research community has a responsibility to conduct studies that are not only rigorous but also directly applicable to policy and practice. This includes focusing on areas identified as gaps, such as the roles of communities, families, and equitable access in engineering and science education.

Educators (Teachers and Curriculum Developers): Teachers' agency in mediating external influences and their ability to strategically interpret policies are crucial for successful curriculum

change. Professional development should aim for deep conceptual change rather than superficial adoption of new methods, helping teachers to integrate problem-solving in authentic ways. Curriculum developers should continue to design materials that align with empirically supported pedagogical innovations, such as integrated STEM and design-based learning.

Parents and Communities: Engagement of families and communities can foster a holistic approach to student development and learning, addressing equity challenges.

5.2 Challenges and Opportunities for Policy-Informed Practice

Several challenges impede the seamless integration of research into policy and practice:

- **Research-Practice Gap:** A gap persists between what research identifies as beneficial and what is consistently implemented in classrooms.
- **Research-Policy Gap:** This pilot study suggests that there may be limited focus on matters related to education policymaking in TED education research.
- **Equity in Technology Access:** Unequal access to advanced digital tools can disadvantage students, despite policy intentions for inclusive learning opportunities.
- **Curriculum Overload and Assessment Pressure:** Excessive content and performance targets restrict the time and flexibility needed for design-based approaches.

However, significant opportunities exist:

- **Collaborative Ecosystems:** Strengthening collaborations among researchers, policymakers, and practitioners can create more responsive and effective ecosystems.
- **Targeted Professional Development:** Challenging underlying conceptual metaphors and foster teachers' epistemological understanding can deepen policy implementation.
- **Leveraging Technology for Equity:** Policies can specifically target investments in technology infrastructure and teacher training to bridge the equity gap.
- **Promoting Critical Dialogue:** Encouraging open discussion about the critiques of TED education, particularly regarding potential disciplinary hegemonies.

6. CONCLUSION

This systematic review illuminates the complex and dynamic interplay among policy, research, and educational practice in Technology, Engineering, and Design education. It reveals that research findings exert influence on policymaking primarily through the conceptual grounding and justification of new educational standards and frameworks, which increasingly advocate for integrated STEM and design-based learning approaches. However, this influence is mediated by several factors, including the critical role of teacher agency, the efficacy of professional

development, the presence of cross-sector collaborations, and persistent equity concerns related to technological access.

6.1 Summary of Key Insights

The review's thematic analysis yielded several key insights:

- Policy documents such as the NGSS and various learning frameworks explicitly integrate research-informed concepts of TED education.
- Empirical research supports specific pedagogical innovations, including engaging design challenges and using suboptimal designs for iterative improvement.
- Technological advancements are transforming TED curricula, yet their equitable adoption remains a significant challenge due to socioeconomic disparities in access.
- Teacher agency is paramount in mediating policy and research into classroom practice. Teachers' ability to strategically interpret and harness policies is crucial.
- While research highlights the importance of student agency, community, and equitable access, these areas remain underrepresented in the broader body of scholarship.

The journey from research insight to widespread, effective policy-informed practice in TED education is complex, characterised by both progressive alignment and enduring challenges.

6.2 Recommendations for Future Research and Policy Development

Based on the synthesis of findings, the following recommendations are proposed:

6.2.1 For Future Research:

(i) Conduct more empirical studies examining the direct causal links between specific research findings and subsequent policy changes.

(ii) Prioritise research focusing on the roles of communities, families, and learner agency in STEM and engineering education to address current gaps in scholarship.

(iii) Investigate the long-term impacts of so-called integrated STEM (iSTEM) and design-based learning approaches on student outcomes.

(iv) Explore the effectiveness of different professional development models in fostering deep conceptual change in teachers' pedagogical beliefs and practices regarding TED.

(v) Include grey literature in future systematic reviews to minimise publication bias and capture a broader perspective of policy formation and implementation.

6.2.2 For Policy Development:

(vi) Develop policies that actively involve teachers and other practitioners in their design and revision processes, recognising their critical role in successful implementation.

(vii) Allocate dedicated resources for comprehensive and sustained professional development that moves beyond superficial training to address teachers' conceptual understanding of TED pedagogy.

(viii) Implement policies that explicitly address equity and access to technology to ensure all students can engage with modern TED curricula.

(ix) Consider the implications of assessment policies on curriculum implementation, ensuring that TED subjects are adequately valued and integrated within the broader educational framework.

(x) Foster critical dialogue on the underlying assumptions of policy frameworks, allowing for continuous adaptation and improvement based on research and societal needs.

6.2.3 Limitations

As a pilot for the search protocol, this study is limited by a number of factors that should be addressed in future larger scale studies, including the: (i) restriction to a single database (which excluded sources not indexed in Scopus); (ii) relatively narrow range of search terms (which may have excluded literature from countries where the K12 TED education subject has a different name); (iii) exclusion of grey literature and other sources (which may provide more reference to policy than peer reviewed journal articles); and (iv) focus on sources that specifically mention "policy" (which may have excluded otherwise impactful studies that did not explicitly refer to policy). However, this paper highlights the relative lack of reference to policy in the TED education research literature, which appears to be a gap that should be addressed by the community.

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What artificial intelligence cannot do: Philosophical insights for technology education in the age of AI

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Abstract

Artificial intelligence (AI) is one of the oldest sub-fields of computer science, but in the last few years it has created a global hype in education primarily due to new and powerful generative AI tools. Just as for many previous technologies, the discourse around AI promises a revolution of instruction, relief from tedious repetitive teaching chores, and an increase in productivity. However, what is missing in these discourses is a philosophical grounding, conceptual clarity, and phenomenological implications of AI in learning situations, specifically in technology education. The aim of this paper is thus to provide a philosophical foundation for discussing the role of AI in technology education, by putting it in the context of Albert Borgmann's device paradigm. The paper engages in a philosophical discussion viewed through the lens of Borgmann's phenomenological philosophy, in which AI is discussed in relation to device and focal practices. The paper ends with five distinct areas of technology education of which we today can say, with Borgmann's philosophy as a backdrop, *what AI cannot do*, together with some suggestions for how focal practices can heighten our use of AI by, paradoxically, relegating it to the periphery.

Key Words: technology education; artificial intelligence; philosophy of technology; Albert Borgmann

1. INTRODUCTION

Artificial intelligence (AI) is one of the oldest sub-fields of computer science, but in the last few years AI as a phenomenon has increasingly permeated public discourse on the future of industry, work, health care, transport, public works, education, and even warfare. New powerful generative AI tools make previous iterations pale in comparison. These tools thus create great hope for the future in that they are believed to revolutionize society in general, and education in particular. The word "hype" is arguably an understatement (e.g., Cerratto Pargman et al., 2024), and there are echoes from the introduction of many previous educational technologies such as TVs and computers in the 20th century: the promise of a revolution of instruction, relief from tedious repetitive teaching activities, and an increase in productivity, although it remains largely unclear what "productivity" would mean in a classroom (Cuban, 1986; Machado-Trujillo, 2021). Much of the discourse on AI and education today thus echoes what Borgmann wrote already in 1984,

that technology “promises to bring the forces of nature and culture under control, to liberate us from misery and toil, and to enrich our lives” (1984, p. 41).

Still, the relationship between educators and technology has been described as a “fickle romance” by Cuban (1986). On the one hand, actors outside of school such as inventors, industry, company, or government representatives often regard teachers resisting new technology as conservative or negative to change. Teachers are seen as overly critical of new technology, despite the existence of – prior or parallel – alternative technologies (Edgerton, 2010; Petrina, 2004). On the other hand, there are teachers who enthusiastically embrace new technology, often slightly before its widespread diffusion, and who thereby also potentially contribute to the further development of the new technology by providing input into how it works in classrooms (cf., Edgerton, 2008). Both these teacher categories know that, as with all technology, educational technology is only effective in so far as it fulfils a purpose, related to a need or problem to be solved in the classroom, but they approach it differently.

In technology education, the response by teachers to the educational technology-focused AI hype described above has been cautious. On the one hand, AI as a phenomenon should be considered part of the technology knowledge domain just like any other technology (Hallström, 2024). On the other hand, the hands-on, material and embodied nature of technology education might make it problematic, at least at present, to implement generative and other AI tools broadly in, for example, design and make activities, construction and production processes, work on various materials, tool instruction, etc. (cf. Tang & Cooper, 2024). In addition, a major concern has to do with the notion of creativity and creative thinking in relation to the tools that designers use, in the light of new generative AI applications (e.g., Schut & Detweiler, 2025). Furthermore, there is the challenge of errors and “hallucinations” produced by Large Language Models, LLMs (Johnson & Hajisharif, 2024), and so on.

What is missing in these responses, however, is a philosophical grounding and conceptual clarity about AI. Discussions about AI in technology education must also be contextualized properly in relation to various AI tools and educational situations. A more pressing concern is how teachers and students experience AI, which is why a philosophical analysis specifically related to the phenomenological implications of AI in learning situations is needed. Only then can a fruitful discussion about real benefits and disadvantages of AI in technology education ensue, for example, in relation to AI as content or as tool – or both.

The aim of this paper is to provide a philosophical foundation for discussing the role of AI in technology education, by putting it in the context of Albert Borgmann’s device paradigm.

2. THE PROMISE OF TECHNOLOGY IN EDUCATION

For the last hundred years, technological advancements have been promoted in education in various ways. Sydney Pressey and the promotion of his Automatic Teacher is perhaps the most well-known example of educational technology that was also coupled with psychometric testing in the 1920s and 1930s (Petrina, 2004). However, there have been many other artefacts such as film projectors, slide projectors, TVs, radios, and computers that have been promoted as aids that

could either individualize or mass-produce teaching and relieve the teacher of more repetitive and burdensome tasks that competed with "real" teaching – demonstration, feedback, and assessment (Cuban, 1986). In addition, especially in the post-World War II era, there was a severe teacher shortage. Hence, educational technology was connected to a general rationalization of education, often through Skinnerian programmed instruction, which was believed to ameliorate the lack of teachers, stimulate economic growth, and save money (Wallin, 2005).

In the bourgeoning field of technology education in the 1980s, the position of technology was self-evident but mainly as subject content in and of itself. The main challenge in defining the new technology curriculum area was to handle the craft and sloyd origins, and the relationship to science education (de Vries, 2018). For some technology educators, therefore, educational technology was disregarded, at least in theory, at the same time as technologies such as overhead projectors, film projectors, computers, wikis, and social media applications were used in practice in classrooms (Loveland, 2018). Today, AI is transforming technology education as generative AI and other AI applications are being brought into classrooms primarily by students, although AI is also commended by some early-adopter teachers (e.g., Su, 2024).

3. AI IN THE PHILOSOPHY OF TECHNOLOGY

The philosophy of artificial intelligence has been a dominating strand especially in the philosophy of computing since the 1960s, but it is arguably also one of the most researched topics in the philosophy of technology in general. For example, the issue of cognition, natural language, and general intelligence has generated a great deal of research, and so has robotics and artificial agents (Boddington, 2023; Brey & Hartz Søraker, 2009; Stolpe & Hallström, 2024; Weizenbaum, 1976). The field of AI ethics has grown exponentially in recent years but has in fact a longer history going back as far as other AI topics in the philosophy of technology (Boddington, 2023; Coeckelbergh, 2020). However, there has been a lack of phenomenological research that situates AI in a learning context, specifically in technology education.

4. BORGMANN: THE DEVICE PARADIGM AND THE FOCAL PARADIGM

The American phenomenologist Albert Borgmann (1937-2023) has not been engaged in philosophical research on AI *per se*. Still, some of his thought has very important implications for how we could view the current state of AI, in technology education and in general. Borgmann (1984) makes an important distinction between two types of technology, or, rather, two types of technological paradigms: technology as a *thing* versus as a *device*. In the first instance, technology as a *thing* is in Borgmann's view "inseparable from its context, namely, its world, and from our commerce with the thing and its world, namely, engagement" (p. 41). Engagement also requires some kind of skill. Borgmann here talks of *focal* things and practices as being related, as well as being expressions of engagement. The word focal or focus is derived from the Latin word for hearth, or fireplace, which used to signify much more than just the production of heat; it was also

the central place, the focus, of the household where the family gathered and carried out cooking and other familial activities.[1]

Borgmann contrasts the focal thing, symbolized by the fireplace, with the *device*, symbolized by a modern central heating plant:

> A device such as a central heating plant procures mere warmth and disburdens us of all other elements. These are taken over by the machinery of the device. The machinery makes no demands on our skill, strength, or attention, and it is less demanding the less it makes its presence felt. In the progress of technology, the machinery of a device has therefore a tendency to become concealed or to shrink (Borgmann, 1984, p. 42).

Tijmes (2001) writes of a further effect of the concealment of devices, that "from the outside of a watch one cannot directly see whether its machinery is digital or analog, meaning that its machinery can be radically altered without affecting the function. This is what Borgmann has in mind when he says that the means and end are sharply separated from each other. The machinery has been set up to produce the end in a safe, easy, instantaneous, and ubiquitous way. It is a pure means, and as such withdraws from sight" (p. 14). There are, however, borderline cases. Ihde (1990) points to the apparent contradiction that a sports car can be less concealed, less in the background than an ordinary car, due to the powerful motor and specific build of the sports car, designed to be in touch with the elements (p. 74). In terms of phenomenology, a sports car with its manual driving therefore requires more focus and engagement than a modern ordinary vehicle with many automatic functions that disburdens the driver.

There is thus, according to Borgmann, an important distinction to be made between the central feature of the device – *disburdenment* – and the pivotal characteristic of the focal thing and practice – *engagement* (Borgmann, 1984, p. 59). According to Dakers and de Vries (2019), the device paradigm therefore leads to different kinds of disengagement on the part of humans, for example, in the way mobile phones make us more focused on our own screens than on communicating with people around us on the bus or even in the home; the device makes demands on us, distracts us, with different reward systems. Yet, the fact that we have the whole world at our fingertips without us making any real effort makes our online relations into products, thus commodified and even disengaged. Further examples from Borgmann (1984, p. 40-56) include microwaving food instead of making it from scratch, or listening to music on a CD, or nowadays online, instead of live in concert. Dakers and de Vries (2019) conclude:

> All this results in our many modern technological devices providing a commodity that requires almost no physical or cerebral activity on our part. Our meals are pre-prepared and cooked at the touch of a button, television takes up considerable hours of our time as we watch pre-made shows designed to entertain us. Our reality is pre-fabricated for us by others. Reality, thus, becomes hyperreal. It disengages us from having any meaningful and tactile relationship with the world. This phenomenon is so omnipresent that Borgmann uses the term 'commodification' to indicate what devices do with

[1] Some of these arguments are developed in relation to postmodernity in Borgmann (1992).

> activities that used to demand effort and yielded deep experiences of happiness and accomplishment (p. 182).

Borgmann goes on to explicate in more detail the nature of the opposing focal paradigm:

> [Focal things] are concrete, tangible, and deep, admitting of no functional equivalents; they have a tradition, structure, and rhythm of their own. They are unprocurable and finally beyond our control. They engage us in the fullness of our capacities. And they thrive in a technological setting. A focal practice, generally, is the resolute and regular dedication to a focal thing. It sponsors discipline and skill which are exercised in a unity of achievement and enjoyment, of mind, body, and the world, of myself and others, and in a social union (p. 219).

Borgmann's critique of the device paradigm should not, however, lead to the conclusion that pre-modern technology is somehow "better" than modern technology. The central feature of modern technology – of devices, if you will – is disburdening humans of cognitive and bodily tasks that we deem too complex or cumbersome. Technology is something that is necessary for our modern society to work, and focal things "thrive in a technological setting" (p. 219). Borgmann instead seeks a reform of technology:

> A reform of the [device] paradigm is even less, of course, a dismantling of technology or of the technological universe. It is rather *the recognition and the restraint* of the paradigm. To restrain the paradigm is to restrict it to its proper sphere. Its proper sphere is the background or periphery of focal things and practices […] The present proposal is to restrict the entire paradigm, both the machinery and the commodities, to the status of a means and let focal things and practices be our ends (p. 220).

The good life, for Borgmann, should therefore be a life where technology as devices only are means to achieving the greater end – focal things and practices (Mitcham, 2014; Tijmes, 2001).

5. DISCUSSION: AI, TECHNOLOGY EDUCATION, AND BORGMANN'S FOCAL PRACTICES

Viewed through the lens of Borgmann's phenomenological philosophy, AI could be regarded as the ultimate device: Most AI applications ordinary citizens deal with, and which students bring to classrooms, are online, text- or image-based, and disembodied, thus separated from human bodily, motor, and much cognitive skill but also from the sources of energy, matter and information required to sustain them. In reality, though, there is a vast technological, material, and socio-economic system that makes the AI application – and several others like it – work (e.g., Crawford, 2021; Hornborg, 2021). However, to use a phrase from Borgmann (1984), the machinery of the AI device has "become concealed", it has shrunk, which has the effect of commodifying knowledge procured through the AI application. Because whatever the AI provides us has made no "demands on our skill, strength, or attention" (Borgmann, 1984, p. 42) the potential disburdenment leads to disengagement (Dakers & de Vries, 2019). Furthermore, when AI is utilized in social media applications to catch the users' attention to collect behavioural

data, we can rightly talk about “distraction technologies” that divert our attention and engagement away from what was originally intended, the original focus (e.g., Schultz, 2025).

The proper use of AI in technology classrooms would be to restrict it to its “proper sphere”, that is, in “the background or periphery of focal things and practices” (Borgmann, 1984, p. 220). Learning is indeed a focal practice, not part of the device paradigm, because it requires engagement to acquire knowledge and skills. When AI takes over certain tasks from citizens, employees, or students and they rely on the output from, say, a generative AI application without cognitive or bodily engagement or critical thinking, that knowledge becomes a commodity that is seemingly valuable, although this always needs to be assessed. Most of all, however, little or no actual learning is possible. On the other hand, using AI as a tool or educational technology as a means to assist some aspect of an activity while the student is still cognitively and/or bodily engaged in achieving the end result – his or her own learning, the focal practice – is a different matter. Ironically, therefore, if we are to gain anything from the AI hype and for AI to matter at all, we need to revert it to the periphery. Only then can AI become meaningful as an educational technology or content in the school, in technology education and all other school subjects.

In technology education specifically, teaching should therefore include AI as knowledge component and learning area, but in the background as a phenomenon or tool among others. Listening to Borgmann, the same principles of engagement and focal practices would apply even here. If we take design as an example, students could incorporate generative AI to suggest design ideas, but they would still need to be wary of the effects that AI could engender, just as any other tool that they use, for example, design fixation (McLellan & Nicholl, 2011; Schut et al., 2019; Schut & Detweiler, 2025). So-called “AI slop” – generically produced AI content with little quality, meaning, or engagement – could also be a threat to distinct, problem-solving design solutions that really lead to true disburdenment where it is needed.

6. CONCLUSION

In conclusion, despite the promises of efficiency and disburdenment in education, *what AI cannot do* is to be the short-cut to good teaching and learning that always seems to be the underlying premise of technological hypes in the school. LLMs have built-in randomness to emulate humanness and learning, but they are really just made up of computation and statistics and lack any authentic connection to real-world contexts. In contrast, human learning is a focal practice that first and foremost requires engagement of the human mind and body. Furthermore, *what AI cannot do* is create better designs or constructions by default, because it requires a person with technological knowledge, skill, and engagement to critically examine AI output. Arguably, “cooperation” between a human designer and an AI agent, leading to co-design (or, co-shaping, see Wellner, 2024) of technological solutions, could potentially be fruitful (Schut & Detweiler, 2025), although hallucinations and incorrect output remain a challenge that cannot only be the responsibility of the students (Flenady & Sparrow, 2025; Rycroft-Smith & Macey, 2025). Thirdly, *what AI cannot do* is give straight, reliable answers to factual questions. This requires critical thinking on the part of both students and teachers when using, for example, generative AI as a source of information on technology or any other topic (Cooper et al., 2025; Johnson & Hajisharif, 2024).

Fourthly, *what AI cannot do*, at least not at present, is provide a physical presence for students and teachers to engage with in technology education which is so inextricably interwoven with our physical and material world; knowing about technology must essentially be an engagement with the material world in the form of tools, materials, equipment, machines, screens, drawings, etc., in which the object of all activities is the *making* of something digital or analog in the physical world (Mitcham, 1994; Tang & Cooper, 2024). However, co-design and co-making with AI as a "cognitive assistant" could be promising, for example, as an extension of computer-aided design, or technology-enhanced learning. Humans have always employed embodied cognition or "hybrid thinking systems" to solve problems using the body or externalising cognitive effort (e.g. Clark, 2025; Dakers, 2019). Finally, *what AI cannot do* yet is function without a great deal of material and energy input to handle large amounts of data and support the training of AI models (Crawford, 2021), to the possible detriment of our common environment and social justice. It seems certainly likely that the development of AI will lead to more energy efficient applications, especially with a current trend to design smaller, local, and less energy consuming AI models. However, more widespread use of AI will simultaneously lead to increased energy demands which is why AI as a background phenomenon would be good even from this point of view.

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Comparing Female High School Students' Difficulty, Knowledge, and Problem-Solving Experience in Technology Design and Engineering Design Activities

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Abstract

This study investigated female high school students' difficulty, knowledge, and problem-solving experience in two types of activities: technological design and engineering design. Using an action research approach, 177 tenth-grade students from an all-girls high school in Taiwan participated in a 12-week intervention. Data were collected using a diagnostic assessment tool developed by this study. Results showed that students exhibited higher knowledge mastery and greater task independence in technology design activities. In contrast, they reported significantly higher difficulty and greater reliance on teacher or peer support during engineering design tasks. Regression analyses indicated that knowledge was not a significant predictor of difficulty, whereas students' greater reliance on external assistance was significantly associated with higher reported difficulty. The study highlights the need for scaffolding strategies and instructional aids that promote self-directed learning, especially for female students with lower knowledge.

Key Words: Engineering design, Design-based, PATT, Difficulty, Female

1. INTRODUCTION

Design-based activities have become a key pedagogical strategy for integrating science, technology, engineering, and mathematics (e.g., English, 2016; Hallström & Ankiewicz, 2023). Wells (2024) emphasized that technology/engineering design-based learning (T/E DBL) serves as a crucial process through which learners acquire disciplinary knowledge. However, according to the *National Science Education Standards*, the *Science Framework for the 2009 National Assessment of Educational Progress*, and the *Next Generation Science Standards*, technological design and engineering design differ in focus (National Research Council et al., 1995; NAEP, 2009; NGSS Lead States, 2013). Technological design emphasizes hands-on, craft-based practices, while engineering design prioritizes the development of solutions, reflective processes, and complex problem-solving (Fan & Yu, 2016; Tzeng & Yu, 2024; Volk et al., 2003). These differences result in varying cognitive demands and learning challenges, particularly for female students who may be more affected by learning activities.

A systematic review by Tzeng and Yu (2024) noted that while technological activities can enhance interest in technology and influence gender-role attitudes, they are less effective in reducing difficulty. Svenningsson et al. (2022) similarly found that female students often view technological tasks as abstract or unfamiliar due to limited conceptual support. Although engineering design supports the application of scientific and mathematical principles, it also requires higher-order thinking, posing challenges for students with limited knowledge (Fan & Yu, 2017; Yu et al., 2020). Based on these distinctions, this study examines differences in difficulty, knowledge, and problem-solving experience among female students participating in technology design and engineering design activities. Through comparative analysis, the study highlights diverse learning trajectories and offers insights for designing more gender-inclusive interdisciplinary curricula. This study compares the effects of technology design and engineering design activities on female high school students through the following research questions:

RQ1: How do female students differ in difficulty, knowledge, and problem-solving experience between technology design and engineering design activities?

RQ2: How do female students with different knowledge levels differ in difficulty and problem-solving experience?

RQ3: To what extent do knowledge and problem-solving experience predict female students' difficulty?

2. THEORETICAL FRAMEWORK

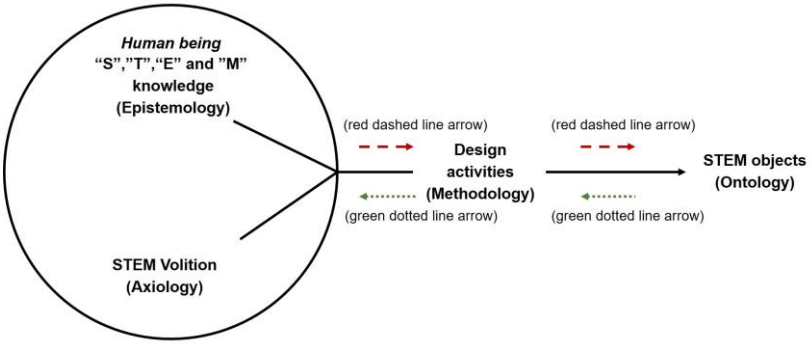
2.1. Theoretical Foundations of Design-Based Learning

Contemporary technology education has shifted from manual craftsmanship toward interdisciplinary integration using design-based activities (e.g., English, 2016; Hallström & Ankiewicz, 2023). Wells (2024) notes that 30% of recent research (2014–2024) on design-based learning occurs within the integration of disciplines. Technology/engineering design-based learning (T/E DBL) have been recognized as an inspiring instructional strategy. This approach positions design not just as a heuristic for acquiring knowledge, but as a process through which new knowledge is discovered (Wells, 2024). Design-based activities are constructivist, fostering knowledge generation through iterative design and reflection. This aligns with Hallström and Ankiewicz's (2023) philosophical framework, which emphasizes bidirectional interactions between learners and learning activities (Figure 1)

2.2. Technological Design and Engineering Design Activities

Design-oriented activities fall into two categories: technological design and engineering design. *The National Science Education Standards* (NSES) defined technological design as an instructional strategy for learning science (National Research Council et al., 1995), and the *Science Framework for the 2009 National Assessment of Educational Progress* (NAEP) reframed it as systematic scientific application to real-world problems (National Assessment Governing Board, 2008). Both definitions emphasize activities anchored in students' existing scientific knowledge, promoting science–technology linkages and hands-on skills.

Figure 1.
Hallström and Ankiewicz (2023)'s philosophical framework for design-based transdisciplinary curricula



The *Next Generation Science Standards* (NGSS) describe engineering design as a systematic and iterative design process—define, develop solutions, and optimize—grounded in empirical evidence (NGSS Lead States, 2013). It aims to develop complex problem-solving competence and specifies learning progressions across grade bands (e.g., Grades 9–12).

As McCormick (1997) emphasized, learning in technological activities should address not only 'know how' (procedural knowledge) but also 'know that' (conceptual knowledge), which enables explanation and understanding. This evolution—from technological design's focus on foundational understanding and hands-on proficiency to engineering design's emphasis on problem-solving—marks a significant shift in cognitive complexity. Although policy definitions clarify the two designs in definition, they do not fully capture differences in nature, instructional strategies, implementation, and process specificity.

Recent studies identified key differences: technological activities emphasize experiential tasks, hands-on practice, and reflective design processes, but only approaches that incorporate technological tools and higher-order thinking have been shown to improve students' difficulty and conceptualizations of technology (Tzeng & Yu, 2024). Traditional implementations focused on craft-based skill development, whereas innovative programs emphasize problem-solving (Volk, Yip, & Lo, 2003). Although comprehensive process for technological design are limited, engineering design has been systematically structured through established processes such as the 6E (Burke, 2014), the Teach Engineering Design Process (TeachEngineering.org, 2020), and the process by Fan and Yu (2016), which includes identifying problems with constraints and limitations, developing possible solutions, perform a predictive analysis and model the prototypes, test and modify the best prototype, evaluate the final design, and redesign and optimize.

Based on these developments and related studies, we argue that technological activities have evolved from initial exposure to technology, through craft-based and skill-oriented design tasks, toward engineering design emphasizing reflection, higher-order thinking, and iterative design process (see *Table 1*).

Table 1.
Comparison between technological design and engineering design activities: definition, nature, instructional strategy, implementation, and process

Aspect	Technological Design	Engineering Design	Source
Definition	Tasks are conducted within students' existing scientific knowledge to support conceptual understanding and hands-on skill development.	A process focused on developing solutions to human-centred problems through the application of scientific knowledge, aiming to enhance problem-solving abilities.	National Research Council et al. (1995); National Assessment Governing Board (2008); NGSS Lead States (2013)
Nature, Instructional Strategy, Implementation, and Process	- Hands-on activities -Technological tools usage -Craft-based approach emphasizing skill development - Lacks a comprehensive procedural model in the literature	- Reflective design process - Technological tools usage and higher-order thinking - Emphasis on problem-solving - Involves iterative design process, e.g., developing solutions, modelling, testing, evaluating, and optimizing	Tzeng and Yu (2024); Volk, Yip, & Lo (2003); Fan & Yu (2016)

2.3. Research on Female Students' Participation in Design-Based Activities

Early research from the Pupils' Attitudes Toward Technology (PATT) revealed that gender influences students' participation in technological activities (Raat & de Vries, 1985). Systematic reviews indicate that while technology curricula can enhance student interest and positively influence gender-role attitudes, difficulty remains a barrier to learning (Tzeng & Yu, 2024). Girls also require a broader conception of technology to stay engaged (Svenningsson et al., 2022). Although short-term technological experience can raise interest, they are insufficient to reduce learning difficulty (Boeve-de Pauw et al., 2022).

Engineering design supports the application of scientific and mathematical principles and improves learning outcomes (Fan & Yu, 2017; Yu et al., 2020; Tzeng et al., 2024). However, it also demands higher-order thinking, posing cognitive challenges for students with limited prior knowledge (Fan & Yu, 2017; Yu et al., 2020). Tzeng et al. (2024) found that girls showed less positive attitudes than boys toward engineering-focused STEM curricula. Qualitative studies further report that girls often experience boredom and frustration during design activities, which may lead to disengagement, even if the activities were not explicitly categorized as technological design or engineering design (Chittum et al., 2017; Dohn, 2013).

Drawing from the above literature, technological design activities are defined by tasks bound by the existing knowledge a given student possesses, emphasizing conceptual understanding and

hands-on practice—often craft-based and skill-oriented. On the other hand, engineering design is focusing on solution development and reflective, cognitively demanding iterative design process that include modelling, testing, evaluating, and optimizing. Both types of design activities shape girls' cognitive belief and behavioural responses. Girls may encounter challenges and demonstrate conceptual understanding in both, yet specific differences remain unclear. They may also tend to withdraw when facing difficulty rather than persist. Therefore, this study employs an action research approach to examine how technological design and engineering design activities differentially affect female high school students.

3. METHODOLOGY

3.1. Action Research Method

This study adopted an action research approach (Kemmis et al., 2013) to examine female students' difficulty, knowledge, and problem-solving experience in technological design and engineering design activities. Action research was appropriate due to the practical implementation of design-based activities in authentic classroom settings. The study proceeded in four stages: Planning: A curriculum was selected, and technology teachers were invited to co-develop the implementation plan. Experts in interdisciplinary curriculum helped design a diagnostic assessment tool, and instructors capable of delivering both types of activities were recruited. Action: The curriculum was implemented, and data were collected after instruction. Observation: All data were subjected to statistical analysis. Reflection: A research report was compiled based on the findings.

3.2. Participants and Implementation Context

Participants were 10th-grade students from a metropolitan all-girls high school in Taiwan. Two technology teachers implemented the course with 186 students. The course, *Living Technology*, was conducted in the school's technology classroom. Upon completing all curriculum activities, students took a diagnostic assessment developed for this study. After excluding nine incomplete responses, 177 valid questionnaires were analysed.

3.3. Technological Design and Engineering Design Activities in Current Study

The curriculum was developed based on characteristics of design-based activities identified in above literature and adapted from the interdisciplinary curriculum module proposed by Tzeng et al. (2018). Expert teachers in electrical engineering, physics, and art collaboratively designed the activities. They had three years of collaborative experience in interdisciplinary curriculum development and over five years of professional teaching experience in their respective fields. The 12-week curriculum consisted of six weeks of technological design activity and six weeks of engineering design activity, conducted in weekly 2-hour sessions.

The theme of the technological design activity was LED circuit board construction. Students applied prior science knowledge (e.g., additive colour mixing, resistance calculation) to work with LED components, soldering tools, and basic circuits. They engaged in Craft-based practice by building functional LED boards using DIP switches. The theme of the engineering design

activity was 3D lampshade design. Students applied the mandala thinking method and used SketchUp software for modelling and testing. The activity emphasized cognitive exploration and iterative design optimization.

The instructional processes were adapted from Fan and Yu's (2016) framework, following a shared sequence: identifying problems, solutions, planning, practicing, testing and evaluation, and improvement/redesign. In the technological design activity, instruction emphasized "making to explore", with teacher-provided solutions and hands-on practice. Students used pre-packaged materials to create functioning products, engaging in testing and debugging. In the engineering design activity, instruction followed "thinking before making", focusing on constraints and limitations, solutions development, and reflection. Students modelled prototypes with software and iteratively refined their designs through testing, evaluation, and optimization (see *Table 2*).

Table 2.
The instructional processes of technological design and engineering design activities

	Technological Design	Engineering Design
Theme and Objective	LED Circuit Board Project: Students apply prior knowledge of additive colour mixing and resistance calculation in a Craft-based activity to understand control component functions.	3D Structural Lampshade Project: Students engage in cognitive tasks using the mandala thinking method to develop 3D design solutions and explore optimized forms.
1. Identify Problems	Explain prior scientific knowledge (e.g., additive colour mixing, resistance), introduce material kits and soldering tools.	Define design theme using the mandala thinking method; guide observation of real-world contexts and identify constraints and limitations in materials and tools.
2. Solutions	Introduce control component options for LED circuit boards; familiarize students with a DIY LED light-adjusting board.	Develop solutions for 3D structural concepts; introduce SketchUp as the design software.
3. Planning	Analyse design requirements, DIP switch logic, and component selection; teach soldering techniques.	Plan 3D designs using SketchUp; assess output feasibility via digital modelling.
4. Practicing	Practice soldering and material handling; assemble components to achieve product functionality.	Build 3D prototypes based on design goals and complete structural modelling.
5. Testing and Evaluation	Test DIY LED board and DIP switch functions; troubleshoot for proper operation.	Conduct output tests to evaluate whether designs meet objectives; use data when applicable.
6. Improvement/Redesign	Encourage debugging and refinement through hands-on activity.	Encourage design optimization through reflection and iterative redesign.

Note. LED = Light-emitting diode; DIP = Dual in-line package.

3.4 Diagnostic Assessment Tool

The diagnostic assessment tool was developed in collaboration with three experienced *Living Technology* teachers, each recruited for their over three years of teaching experience to support

curriculum implementation and item development. Additionally, three university scholars with more than ten years of interdisciplinary curriculum research experience in technology and engineering were invited to review and revise the assessment items.

Consensus-building focused on aligning science, technology, engineering, art, and mathematics concepts embedded in instructional processes with item construction. The three teachers initially developed seven knowledge test items for the technological design activity and eight for the engineering design activity. The interdisciplinary experts provided revision suggestions—technological design items were aligned with Taiwan's technology curriculum guideline (e.g., understanding of control component functions), while engineering design items reflected practical contexts (e.g., orthographic projection concepts in software operation).

A pilot test involving 184 female high school students was conducted. Based on item difficulty indices (Pi = 0.2–0.8) and discrimination indices (Di > 0.2), four technological and five engineering items were selected. Using these items as a foundation, additional questions assessing difficulty and problem-solving experience were developed and revised by the three interdisciplinary curriculum experts. Each item set included three components: difficulty, knowledge test, and problem-solving experience, resulting in nine item sets and 27 questions.

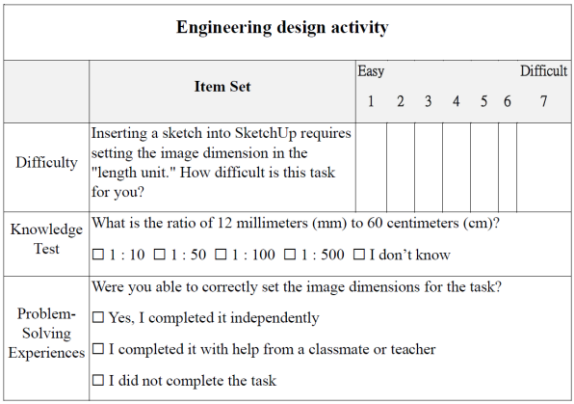
Following implementation, six knowledge items met the criteria for difficulty and discrimination. These, along with their associated difficulty and problem-solving experience questions, formed the final six item sets used for data analysis, comprising a total of 18 items (see *Figures 2* and 3 and *Table 3*).

Figure 2.

An example of item Set for technological design activity

Technological design activity									
	Item Set	Easy							Difficult
		1	2	3	4	5	6	7	
Difficulty	How difficult is it for you to identify the color outcomes produced by additive color mixing?								
Knowledge Test	How many colors can be produced through additive color mixing? ☐ Three ☐ Four ☐ Seven ☐ Infinite colors ☐ I don't know								
Problem-Solving Experiences	Were you able to complete the task of identifying the colors produced by additive color mixing independently? ☐ Yes, I completed it independently ☐ I completed it with help from a classmate or teacher ☐ I did not complete the task								

Figure 3.
An example of item Set for engineering design activity



Engineering design activity								
	Item Set	Easy						Difficult
		1	2	3	4	5	6	7
Difficulty	Inserting a sketch into SketchUp requires setting the image dimension in the "length unit." How difficult is this task for you?							
Knowledge Test	What is the ratio of 12 millimeters (mm) to 60 centimeters (cm)? ☐ 1 : 10 ☐ 1 : 50 ☐ 1 : 100 ☐ 1 : 500 ☐ I don't know							
Problem-Solving Experiences	Were you able to correctly set the image dimensions for the task? ☐ Yes, I completed it independently ☐ I completed it with help from a classmate or teacher ☐ I did not complete the task							

Table 3.
Difficulty Indices and Discrimination Indices of Knowledge Test Items

Item	*PiH*		*PiL*		*Pi*	*Di*	Decision
	frequency	percentage	frequency	percentage			
Technological design activity							
Item 1	47	81.0	17	27.0	54	54	Retain
Item 2	57	98.3	57	90.5	94	8	Remove
Item 3	57	98.3	31	49.2	74	49	Retain
Item 4	56	96.6	47	74.6	86	22	Retain
Engineering design activity							
Item 1	41	70.7	15	23.8	47	47	Retain
Item 2	57	98.3	45	71.4	85	27	Retain
Item 3	58	100.0	52	82.5	91	18	Remove
Item 4	48	82.8	24	38.1	60	45	Retain
Item 5	58	100.0	60	95.2	98	5	Remove

Note. *PiH* = Percentage of correct answers in the high-scoring group. *PiL* = Percentage of correct answers in the low-scoring group. *Pi* (Difficulty Index) = (*PiH* + *PiL*) / 2. *Di* (Discrimination Index) = *PiH* – *PiL*.

3.5 Attributes of the Diagnostic Assessment Subscales

As shown in *Table* 4, for the technological design activity, the mean difficulty score was 2.22 (*SD* = 1.09), with strong internal consistency (α = .81), indicating low-to-moderate difficulty. The average knowledge score was 2.12 (*SD* = 0.74), reflecting fair understanding. The mean problem-solving experience score was 1.17 (*SD* = 0.30), suggesting most students completed tasks independently.

For the engineering design activity, the mean difficulty score was significantly higher at 3.40 (*SD* = 1.35), also with strong reliability (α = .80). The mean knowledge score was 1.92 (*SD* = 0.77), slightly lower, possibly due to increased complexity and principal application. The problem-solving experience score was 1.52 (*SD* = 0.41), indicating students more frequently relied on peer or teacher assistance.

Table 4.
Descriptive Attributes of Diagnostic Assessment Subscales

	M	*SD*	Cronbach's α	Range	Scoring Description
Technological design activity					
Difficulty	2.22	1.09	.81	1-7	7-point Likert scale: 1 = very easy, 7 = very difficult
Knowledge test	2.12	.74	N/A	0-3	0 = all incorrect; 1 point per correct item
Problem-solving experience	1.17	.30	N/A	1-3	1 = completed independently; 2 = with peer/teacher help; 3 = not completed
Engineering design activity					
Difficulty	3.40	1.35	.80	1-7	7-point Likert scale: 1 = very easy, 7 = very difficult
Knowledge test	1.92	.77	N/A	0-3	0 = all incorrect; 1 point per correct item
Problem-solving experience	1.52	.41	N/A	1-3	1 = completed independently; 2 = with peer/teacher help; 3 = not completed

3.6 Data Analysis Methods

To address the research questions, this study employed paired-sample *t*-tests, independent-sample *t*-tests, and regression analysis.

4. RESULTS

4.1. Differences in Difficulty, Knowledge, and Problem-Solving Experience

A paired-sample *t*-test was conducted to address RQ1 (see *Table 5*). Students reported significantly greater difficulty in the engineering design activity ($t = -11.99$, $p < .001$), with a mean difference of -1.18, indicating increased challenge and pressure.

For knowledge, scores were slightly higher in the technological design activity (mean difference = 0.21; $t = 2.84$, $p = .01$), suggesting that students had a better grasp of knowledge in the technological design activity.

Regarding problem-solving experience, students were more likely to seek assistance in engineering design (mean difference = -0.35; $t = -11.04$, $p < .001$), indicating that students were more likely to seek assistance from teachers or peers during the engineering design activity.

Table 5.
Comparison of difficulty, knowledge, and problem-solving experience between technological design and engineering design activities

	Mean Difference	*SD*	95% Confidence Interval of the Difference	*t*	*df*	*p* (2-tailed)
Tech difficulty – Eng difficulty	-1.18	1.31	[-1.37, -0.98]	-11.99	176	0.00***
Tech knowledge – Eng knowledge	0.21	0.98	[0.06, 0.35]	2.84	176	0.01**
Tech problem-solving experience– Eng problem-solving experience	-0.35	0.42	[-0.42, -0.29]	-11.04	176	0.00***

Note. ***p < .001, **p < .01

4.2. Differences by Knowledge Level

To address RQ2 (see *Table* 6), participants were divided into high- and low-knowledge groups. In the technological design activity, no significant differences were found in difficulty or problem-solving experience between the groups. However, in engineering design, the low-knowledge group reported higher difficulty (M = 3.77, SD = 1.39) than the high-knowledge group (M = 3.24, SD = 1.25; t = -2.16, p = .03). Similarly, their problem-solving experience scores were higher (M = 1.63 vs. 1.47; t = -2.04, p = .04), indicating greater reliance on external support. Both results were statistically significant with moderate effect sizes (Cohen's $d \approx 0.4$).

Table 6.
Comparison of Difficulty and Problem-Solving Experience between High-Knowledge and Low-Knowledge Groups

	High-Knowledge Group		Low-Knowledge Group		*t* value	*p*	Cohen's *d*
	M	*SD*	*M*	*SD*			
Technological design activity							
Difficulty	2.20	1.08	2.31	1.16	-.56	.57	.10
Problem-Solving Experience	1.14	.26	1.19	.32	-.88	.38	.17
Engineering design activity							
Difficulty	3.24	1.25	3.77	1.39	-2.16	.03*	.40
Problem-Solving Experience	1.47	.39	1.63	.43	-2.04	.04*	.39

Note. *p < .05

4.3. Predictors of Difficulty

Multiple regression analyses (see *Table 7*) were conducted to examine whether knowledge and problem-solving experience predicted students' difficulty in technological design and engineering design activities. In both types of design activities, knowledge was not a statistically

significant predictor of difficulty, as indicated by nonsignificant p-values (p = .13 and p = .10, respectively) and 95% confidence intervals that included zero.

In contrast, problem-solving experience—specifically, students' greater reliance on external support such as peers or teachers—was a significant positive predictor of difficulty in both activity types. In the technological design activity, the unstandardized coefficient (B = 1.52, SE = 0.25) with a 95% CI of [1.03, 2.01] and a highly significant t-value (t = 6.11, p < .001) indicated a substantial relationship. Similarly, in the engineering design activity, B = 1.82 (SE = 0.20), CI = [1.42, 2.22], and t = 8.96 (p < .001), again confirming statistical significance. These findings suggest that students who relied more heavily on others were more likely to perceive the activities as difficult, regardless of the design type.

Table 7.
Regression Analysis of Knowledge and Problem-Solving Experience on Difficulty

Activity Type	Variable	*B*	*SE*	*t*	*p*	95% CI
Technological design activity			Difficulty			
	Knowledge	-.15	.10	-1.51	.13	[-.35, .05]
	Problem-Solving Experience	1.52	.25	6.11	.00***	[1.03, 2.01]
Engineering design activity			Difficulty			
	Knowledge	-.18	.11	-1.64	.10	[-.40, .04]
	Problem-Solving Experience	1.82	.20	8.96	.00***	[1.42, 2.22]

Note. ***p < .001

5. DISCUSSIONS

First, the analysis showed significant differences in difficulty, knowledge, and problem-solving experience across the two types of design-based activities. This indicates that the nature of the design task influences students' cognitive belief and behavioural responses.

Second, in the technological design activity, no significant differences were found between high- and low-knowledge groups in difficulty or problem-solving experience. This suggests that such activities impose relatively uniform cognitive demands, making them a suitable entry point for girls to engage in design-based learning and build confidence. In contrast, in the engineering design activity, low-knowledge girls reported significantly higher difficulty and weaker independent problem-solving performance. This highlights knowledge as a key factor in shaping cognitive belief and behavioural responses in more complex design tasks.

Third, in both design-based activities, problem-solving experience significantly predicted difficulty, while knowledge did not. This suggests that difficulty is more closely linked to students' experiences of challenge and reliance on external support, rather than to knowledge alone.

Future curriculum design involving engineering design tasks should offer more self-directed guidance and support—particularly for girls with lower knowledge—through phased instruction and preparatory scaffolding (e.g., teaching for forethought) to close learning gaps and enhance participation. Additionally, since difficulty often arises from relying on others rather than self-directed efforts, educators should incorporate strategies that promote independent problem-solving, such as AI-assisted tools and instructional videos, to support students in overcoming challenges autonomously.

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An Educational Device based on Holographic Projectors to Simulate Arabic Sign Language for Enhancing Learning in Deaf Children

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Abstract

In primary education, children with disabilities often face greater challenges in language acquisition compared to their peers without disabilities. This difficulty is compounded by the complexity of sign language and the limited ability of non-disabled parents to assist their children, as they are typically not proficient in sign language. This study proposes a device based on holographic projectors that simulates Arabic Sign Language, aimed at enhancing learning for deaf children. The device demonstrates the various letters and their shapes. Leveraging holographic projector technology, this solution is designed to be cost-effective and accessible for parents, providing an innovative tool to support children's education at home.

Key Words: Deaf children, Learning difficulties, Arabic Sign Language, Holographic Projector.

1. INTRODUCTION

Sign language is the primary mode of communication for deaf and hard-of-hearing individuals, using visual gestures, facial expressions, and body movements to convey meaning. Different countries have their own distinct sign languages, such as German Sign Language (DGS) in Germany (Haug, 2011), French Sign Language (LSF) in France (Bertin-Lemée et al., 2022), and American Sign Language (ASL) in the United States (Munib et al., 2007). For international communication, International Sign (IS) (Supalla & Webb, 2013) serves as a simplified, cross-linguistic system often used in global forums. In the Arab world, Arabic Sign Language (ArSL) functions as a regional variant. While still developing, recent efforts have focused on documenting and standardising ArSL to promote its widespread adoption and uniform usage across Arab nations (Abdel-Fattah, 2005; Aliwy & Ahmed, 2021).

Keating and Mirus (2003) observe that deaf youth, often a small minority in predominantly hearing public school settings, are particularly vulnerable to communicative isolation. Building on this concern, Marschark and Knoors (2012) investigated the cognitive functioning of deaf learners and noted that their lower academic performance compared to hearing peers may be linked to underlying cognitive differences. These disparities, they suggest, are likely to persist throughout the educational process, as deaf students tend to process information in distinct ways that can profoundly influence their academic development.

Learning sign language poses notable challenges for children, particularly when the language itself presents additional complexity, as is the case with Arabic Sign Language. Like spoken languages, sign languages are living systems that evolve over time. Arabic Sign Language is still undergoing development and has yet to be fully standardised (Alayed, 2024). A major challenge lies in its considerable variation across Arab countries and even within individual regions, largely shaped by local dialects. In addition, historical influences such as colonisation have introduced foreign elements into these sign systems. For example, the sign languages used in Maghreb countries differ significantly from those in eastern Arab nations (Tharwat et al., 2021). While certain signs may overlap, a substantial divide remains, primarily due to the lack of a unified educational framework and consistent linguistic standardisation.

Continuous technological advancement is gradually overcoming many of the obstacles related to sign language acquisition. A variety of innovative tools and systems are being created to facilitate both communication and learning. Moreover, technology is transforming how data are gathered, enabling access to new types of information that were previously unavailable (Lucas et al., 2013). In addition, artificial intelligence–driven tools for sign language recognition (Alabduallah et al., 2025; Rachmawati et al., 2023; Zholshiyeva et al., 2025) and simulation (Nedjar & M'hamedi, 2024) are playing a vital role in improving educational outcomes and promoting greater accessibility for deaf communities.

Holographic projectors are increasingly being adopted in educational environments as assistive technologies, appreciated for their cost-effectiveness and their capacity to deliver information in a highly engaging and interactive way (Al-Modafar, 2025; Salloum et al., 2024).

This study is guided by the question: *How can a holographic projector-based system be designed and implemented as an assistive educational tool for deaf children?* It supports the broader goal of promoting equal access to technology education, with a particular emphasis on the inclusion of students with disabilities.

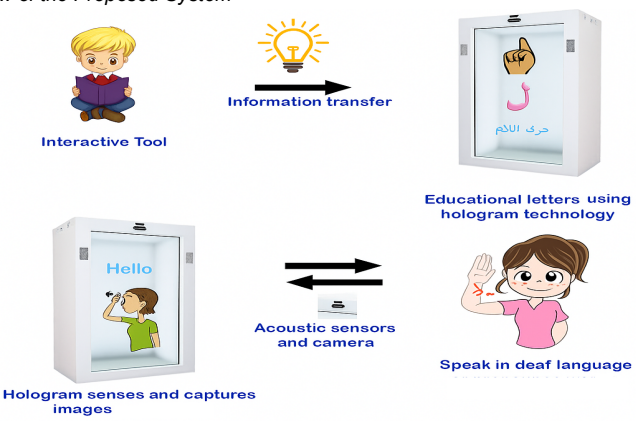
In this paper, we propose the use of a holographic projector to simulate Arabic Sign Language as a means of enhancing learning for deaf children. We selected this technology specifically because it can be accessible to parents, allowing them to support and reinforce their deaf child's sign language learning at home.

The remainder of this paper is structured as follows: Section 2 describes the materials and methods employed in the study. Section 3 presents the evaluation results, followed by a discussion in Section 4. Finally, Section 5 provides the conclusion.

2. MATERIAL AND METHOD

In this work, we present an interactive system utilising a hologram projector to simulate Arabic Sign Language (see Figure 1). The system is designed to assist parents in supporting their children's learning process. It includes a control panel where pressing a specific button triggers the holographic display of the corresponding sign language letter. Additionally, the system is equipped with a recognition module based on artificial intelligence, capable of identifying signs performed by the student and displaying the associated letter—thereby enhancing interactivity and engagement.

Figure 1.
General Overview of the Proposed System



2.1. Definition of Hologram

A hologram is a three-dimensional image created using the process of holography, a technique pioneered by physicist Dennis Gabor. Unlike conventional photographs that capture only light intensity, holography records both intensity and phase, allowing the image to convey depth and realism. This means the image can be viewed from multiple angles with a lifelike perspective. The technique relies on laser light, using interference and diffraction to reconstruct the wavefront of the original object. As a result, holography produces a natural 3D representation without the need for special glasses (Prado Ortega et al., 2020).

2.2. Recognition Module

In this study, MobileNet (Howard et al., 2017) was adopted as the primary deep learning architecture for sign language recognition, chosen for its efficiency and suitability in resource-limited environments. MobileNet is a lightweight convolutional neural network (CNN) that employs depthwise separable convolutions to significantly reduce the number of parameters and computational requirements, while still achieving competitive accuracy. These characteristics make it ideal for deployment in embedded systems and real-time applications, such as our holographic projector-based learning platform. Its compact size, rapid inference speed, and ability to function effectively on low-power devices enable seamless integration into assistive technologies, ensuring both accessibility and scalability.

Within our system, the CNN processes and classifies visual inputs of Arabic Sign Language gestures, enabling real-time recognition and interaction within the holographic projection environment. This close integration between CNN-based gesture recognition and the system's pedagogical objectives fosters an engaging, accessible, and interactive learning experience for deaf children.

2.2.1. Dataset

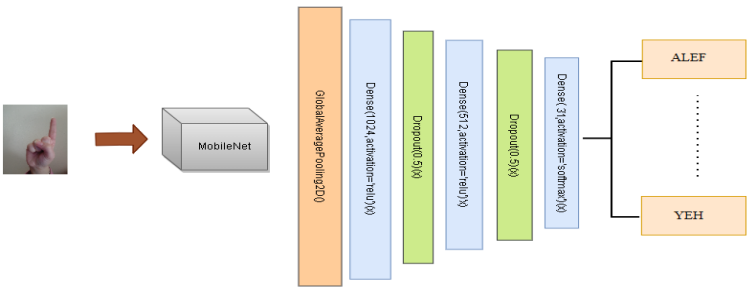
To train and evaluate the recognition module, we used the RGB Arabic Alphabet Sign Language (AASL) dataset proposed by Al-Barham et al. (2023), which contains 7,857 raw and fully annotated RGB images covering the entire Arabic Sign Language alphabet (see Figure 2).

Figure 2.
Arabic Sign Language Letters from RGB Arabic Alphabets Sign Language Dataset (Al-Barham et al., 2023)

3. RESULTS

We applied transfer learning by initialising the MobileNet-based CNN model with pre-trained ImageNet weights. To further optimise the model's performance, additional layers were integrated through fine-tuning, including GlobalAveragePooling, Dense, and Dropout layers, as illustrated in Figure 3.

Figure 3.
Our model based on MobileNet



The performance of the proposed model was evaluated using four key metrics: Accuracy, Precision, Recall, and F1-score.
Accuracy reflects the ratio of correct predictions to the total number of predictions, offering an overall measure of the model's performance.
Precision measures the proportion of true positive predictions out of all positive predictions made by the model, indicating its ability to minimise false positives.
Recall (also known as sensitivity) indicates the proportion of actual positive cases that were correctly identified, assessing the model's ability to detect relevant instances.
F1-score is the harmonic mean of precision and recall, providing a balanced evaluation that considers both false positives and false negatives.

The corresponding formulas are:

$$\text{Accuracy} = \frac{\text{TP} + \text{T N}}{\text{TP} + \text{T N} + \text{FP} + \text{F N}} \tag{1}$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \tag{2}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{3}$$

$$\text{F1-score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \tag{4}$$

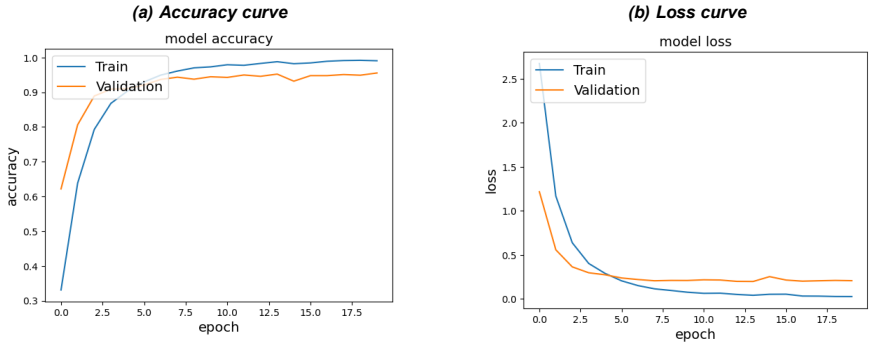
where:
TP = True Positives,
TN = True Negatives,
FP = False Positives,
FN = False Negatives.

Figure 4a presents the accuracy values during the training and validation phases. We observe a smooth increase in accuracy over the epochs. The model based on the MobileNet architecture begins with an initial accuracy of 0.63, demonstrating good generalisation capability from the early stages of training. As training progresses, the validation performance steadily improves, reaching an accuracy of 0.95 by the 20th epoch.

Figure 4b illustrates the loss values during training and validation. A consistent decrease in loss is observed throughout the epochs. For MobileNet, the training loss starts at around 1.3. However, the validation loss decreases steadily over time, indicating effective learning.

After the training phase, the model was tested on the test set, achieving an accuracy of 95%, a precision of 96%, a recall of 95%, and an F1-score of 95%. These results, obtained using the AASL (Arabic Alphabet Sign Language) dataset, are considered satisfactory.

Figure 4.
Training and validation performance of the MobileNet-based model



4. DISCUSSION

Previous studies have examined the use of hologram-based sign language interpreters (Waghmare, 2024; Yang et al., 2022), yet their application as instructional tools in primary education remains underexplored (Fokides & Bampoukli, 2024). A notable example is the work of Adamo-Villani et al. (2017), which introduced a mixed-reality system enabling real-time translation of mathematics lessons via 3D holograms directly in the classroom.

The present work demonstrates the potential of hologram technology as a practical, low-cost, and impactful educational tool. Despite modest implementation requirements, it can significantly enhance learning experiences, fostering greater engagement and motivation among students and parents (Fokides & Bampoukli, 2024), while improving accessibility and comprehension.

4.1. Technology Education Aspect

The proposed holographic projector system is grounded in principles of accessibility, inclusivity, and active learner engagement. Drawing on visual learning theory, it employs 3D holographic projections to present Arabic Sign Language clearly and interactively, thereby improving comprehension and retention. From a technology education perspective, it serves both as a teaching aid and as an example of applied Information and Communication Technology (ICT) innovation, familiarizing educators and students with deep learning and holography. This dual function advances technological literacy and aligns with the broader objectives of technology education.

4.2. Current and Future Work

This study reports the design and evaluation of a hologram-based system built on a public Arabic Sign Language dataset. Pilot testing is underway with deaf children aged 6–8 years at a specialised primary school for hearing-impaired students in Algeria. Sessions are held in a controlled classroom environment, supported by a sign language interpreter and the students' regular teachers to ensure clear communication and comfort. Multiple sessions over the course of a year are planned to monitor and assess the learners' progress, providing insights for system refinement and broader deployment.

5. CONCLUSION

In this paper, we present a portable educational device based on hologram technology, specifically designed to support the learning needs of deaf children. The proposed device is capable of generating images and providing visual outputs—such as hand gestures representing sign language. Its primary objective is to facilitate interactive learning of letters and words for children with hearing impairments. The hologram captures the child's image and transforms it into an animated character that communicates using sign language. To enable sign language recognition, we integrated an artificial intelligence system based on the MobileNet model, trained on the RGB Arabic Alphabet Sign Language (AASL) dataset. The system achieved an accuracy of 95% and a precision of 96%, demonstrating the effectiveness and potential of the device in educational contexts.

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Improving Professional Vision – Professionalisation of Career Changers in STEAM Teaching

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Abstract

The growing shortage of qualified teachers in STEAM subjects poses a major challenge for education systems. One promising response is the qualification of career changers and out-of-field teachers. However, effective teaching requires the ability to swiftly and appropriately interpret classroom situations - a competence known as professional vision (pv), considered crucial for teaching quality. While instruments to assess pv exist, research on its role in technical and scientific disciplines - especially among novice, career changers and out-of-field teachers - is still limited. This paper presents a part of the *ProQ-STEAM* project, which addresses this gap through a quasi-experimental design. A three-part training program combines microteaching, video vignettes, and eLearning modules (from the *VidNuT* project) to foster pv. Changes in teaching quality are assessed via pre/post video analysis using a standardized observation tool. Preliminary interviews with prospective teachers and lecturers ($N_{PT} = 8$; $N_L = 2$) explored added value and barriers; accordingly, an expert norm ($N = 6$) was created to rate pv competences. A large-scale study ($N \sim 100$) is currently examining correlations between pv and teaching quality. This article presents the study design and selected results from the preliminary phase of said study, which aimed to ensure data quality and feasibility.

Key Words: Out-of-field teaching, career changers, STEAM-teaching, professional vision of teaching (pv), teacher education.

1. INTRODUCTION

The current shortage of teaching staff presents significant challenges, particularly in STEAM subjects like Technology & Design. In Austria, the demand for subject-specialist teachers is expected to rise sharply by 2027 (Schnider & Braunsteiner, 2024). One response to this development is the integration of career changers and out-of-field teachers. While career changers often show high motivation (Goodwin et al., 2019), they may also lack pedagogical or subject-specific training, placing additional demands on schools (Huber et al., 2023).

Accordingly, effective implementation of further training measures for career changers is required – with a focus on support structures, teaching quality, and learning outcomes (BMBWF, 2021). A key concept in this context is Professional Vision of Teaching (pv) – the ability to perceive, interpret, and respond to relevant classroom events (Blömeke et al., 2015; Lembens et al., 2023a; Meschede, 2014). Pv is increasingly promoted through video-based training, which fosters situation-specific competences and aims to improve instructional quality (Holodynski et al., 2022). This subproject, as part of the *ProQ-STEAM* network, presents an intervention designed to enhance pv and teaching practice among career changers in Technology & Design. After outlining the theoretical foundations, this paper details the intervention and initial findings from the development phase.

1.1. Professional Vision of Teaching

Pv builds on Goodwin's (1994) concept of professional vision, adapted by Sherin (2001) for teaching. It comprises two core components: selective attention (identifying relevant classroom events) and knowledge-based reasoning (interpreting them through professional knowledge) (Sherin & Van Es, 2009; Seidel & Stürmer, 2010).

These elements are further differentiated into dimensions such as describing, interpreting, evaluating, and generating alternative actions (Junker et al., 2020). Pv overlaps with related constructs such as analytical and diagnostic competence but is distinct in its integration of recognition and interpretation. Pv serves as a bridge between knowledge and action (Blömeke et al., 2015; Goreth et al., 2016). It links dispositions (e.g. knowledge, motivation) with observable teaching performance, mediated by situation-specific skills such as perception and decision-making (Krauss, 2020). According to Meschede (2014), both theoretical and practical knowledge are integrated into cognitive schemas, which support quicker, more adaptive reactions in complex situations.

To foster pv, current discourse emphasizes authentic, practice-oriented settings – especially video-based learning. Projects under the German Teacher Education Quality Campaign use classroom videos to support theory-guided, subject-specific competence development (Holodynski et al., 2022; Zucker et al., 2022). These include third-party and self-produced videos. While third-party clips support model learning, self-produced videos enhance reflection, authenticity, and motivation – especially when combined with microteaching and feedback (Junker et al., 2020).

Pv is often assessed via a three-step model (Stahnke & Blömeke, 2022, p. 77):

(i) Perception of relevant situations
(ii) Interpretation
(iii) Decision making

This model helps integrate diverse skills which result in actions which can be reflected.

The positive effect on pv through the use of video-vignettes in the STEM field has been proven by various studies (e.g., Enenkiel, 2022; Meister et al., 2020). However, there is a research gap with regard to the connection between pv and professional teaching practice, which will be addressed in the course of this study.

1.2. Professional teaching practice

Teacher competence directly influences instructional quality and student achievement, as highlighted in models linking professional competence, teaching practice, and learning outcomes (Baumert & Kunter, 2006; Kunter et al., 2011; Krauss, 2020). To assess instructional practice, video analysis is increasingly used for its ability to capture complex classroom interactions from multiple perspectives (Denn & Hess, 2018). Analytical focus (e.g., cognitive activation) is defined in advance, and validated instruments such as coding schemes are recommended for structured observation (Lotz, 2014).

Pioneering studies like the *TIMSS* video studies (1995, 1999) combined video analysis with surveys and interviews, thus offering generalizable insights into teaching practices (Seidel, 2011). Follow-up projects (e.g., *IPN*, *Pythagoras*, *PERLE*) applied similar video-survey designs and were based on opportunity-use models (Hugener et al., 2006; Lotz et al., 2013; Seidel et al., 2006). Unlike the earlier process-product paradigm, which focused narrowly on teacher behavior and learning outcomes, the opportunity-use model incorporates broader contextual factors influencing instruction (Klieme, 2019).

Three core dimensions of instructional quality have emerged: classroom management, cognitive activation, and constructive support (Gräsel, 2020). While classroom management is broadly applicable, cognitive activation is especially relevant to subject-specific instruction (Steffensky & Neuhaus, 2018). Cognitive activation refers to the intellectual challenge within instruction–prompting pupils to engage deeply with content, connect prior knowledge, and reorganize their understanding (Kunter & Trautwein, 2018). According to Leuders & Fauth (2022), this includes:

- "Where to"–orientation toward learning goals,
- "Where from"–linking to prior knowledge,
- "How"–strategies to support cognitive processing.

In STEM-Education, addressing pupils' conceptions is critical for fostering understanding (Gropengießer & Marohn, 2018; Heeg et al., 2021), which makes cognitively activating teaching strategies particularly essential.

1.3. Microteaching

Microteaching emerged in the 1960s to practice specific teaching skills in small groups (Klinzing, 2002). With video integration in the 1970s (Sacher, 2008), it evolved into a method involving short teaching sequences (~15 minutes), video-based feedback, and reflection (Helmke & Weinert, 2022).

Lessons are revied and retaught based on feedback. Hattie's meta-analysis (2009) confirmed its effectiveness ($d = 0.88$), thus prompting widespread adoption under terms such as blended learning or multi-feedback training.

Projects such as *K2teach* (FU Berlin) exemplify modern applications: prospective teachers record their lessons, upload them to a secure platform, and analyze them in digital video groups.

Since the 1990s, case-based video analysis has gained ground, especially through short video vignettes – authentic or scripted scenes depicting subject-specific classroom situations (Rutsch et al., 2017; Seidel, 2022). These vignettes support focused theory-guided reflection on topics such as pupils' conceptions or classroom diversity. The option to replay scenes allows for in-depth discussion without the immediacy of live teaching (Friesen et al., 2020).

Formats vary by realism (real vs. scripted), instructional quality (best practice vs. problematic), or origin (own vs. external teaching). Central to vignette design are purposeful scenario selection and analytical focus (Benz, 2020).

Examples include the *CLIPSS* project, which created two scripted lessons. The two videos portrayed classroom management in two different ways–one script showed successful classroom management whereas the other portrayed "less" successful classroom management (Lenske et al., 2022). As mentioned before, addressing pupils' conceptions is vital in STEM subjects (Gropengießer & Marohn, 2018; Heeg et al., 2021). The *VidNuT* project acknowledges this by developing STEM-specific scripted vignettes for chemistry, physics, technology, and textiles (Lembens et al., 2023b). For this reason, the *VidNuT* vignettes, which are briefly presented below, are adapted in this approach.

2. METHODOLOGY

2.1. Research Questions

Pv (see above) is considered a key factor in improving teaching quality and is increasingly fostered through external video vignettes and self-produced videos, such as in microteaching.

This study examines the connection between pv development and teaching behavior while focusing on the effectiveness of video vignettes–alone or combined with microteaching–in teacher training. Differences between out-of-field teachers, career changers, and subject-approved teachers are analyzed with the aim to create targeted training programs.

The central research question is: *How effective are microteaching elements combined with video vignettes in fostering the teaching competence of career changers in Technology & Design Education*?

Before implementation, quality assurance is essential. This article therefore addresses the following guiding question: *What opportunities and challenges arise in working with the video vignettes?*

2.2. Sample

The sample of the superordinate study includes career changers and technology education teachers from across Austria, recruited through university teacher training programs and from schools.

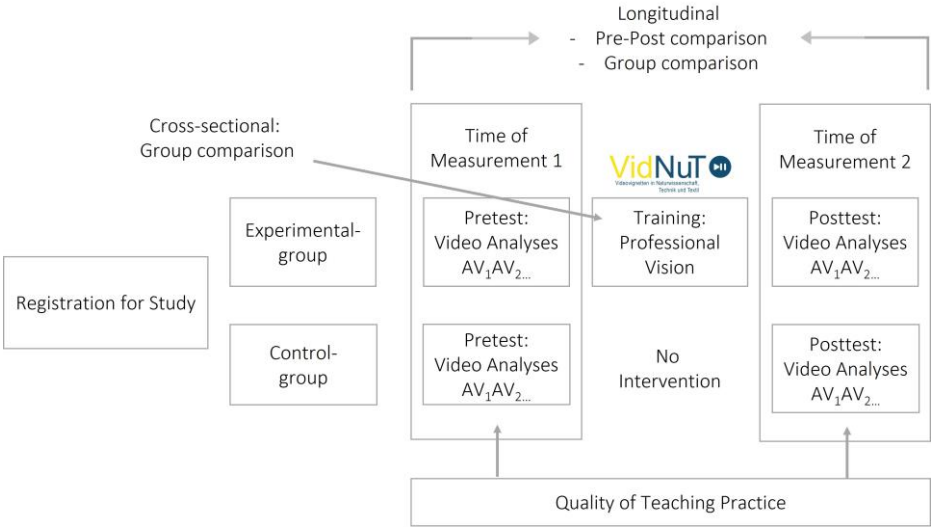
Initial surveys were conducted at the University of Education Tyrol, with additional sites in Salzburg and Vienna planned. To ensure balanced group comparisons, both subject-qualified and out-of-field teachers were included. The target sample size is approximately $N \sim 100$ for the video recordings.

For preliminary investigations, prospective teachers ($N_{PT} = 8$) who worked with the video vignettes were interviewed regarding feasibility. Additionally, lecturers ($N_L = 2$) were interviewed on potentials and challenges of using vignettes. Additionally, five experts in technology education provided input to establish a norm for evaluating pv responses.

2.3. Data collection and instrumentation

The research is based on a quasi-experimental intervention design (see Fig. 1) with video analyses at two times (pre/post). Participants first record three lessons of their choice to assess teaching quality. The core of the intervention involves promoting and measuring pv through eLearning modules and scripted video vignettes from the *VidNuT* -project which focus on pupils' conceptions about robotics.

Figure 1.
Research-Design to assess the Professional Vision and the Quality of Teaching Practice.



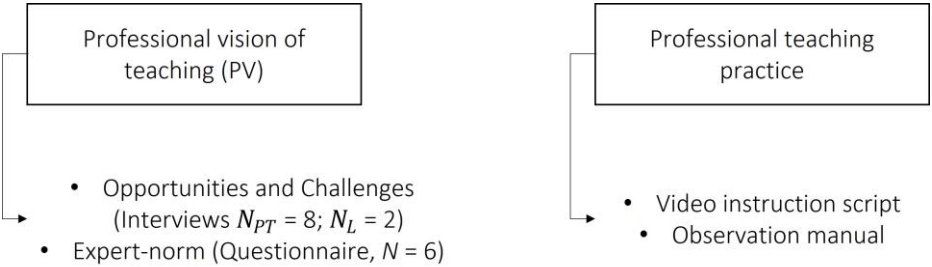
The vignettes follow a three-phase model which includes **diagnosing**, **addressing**, and **reflecting** on learner conceptions, which are based on the three phases described above according to Stahnke and Blömeke (2022). Those three phases are implemented in the following vignettes:

- The vignette "Line-following robots" introduces robotics in 6th grade, thus addressing common preconceptions and basic functionalities using tools like Mentimeter and simplified models (**diagnosing**).
- The vignette "Automated transport systems" builds on real-world video stimuli to promote conceptual change and discuss societal implications (**addressing**).
- The third vignette "Robotics & EVA-Principle" (EVA are the German initials for Input–Processing–Output) focuses on evaluating learning outcomes via Plickers and on reflecting misconceptions regarding the EVA principle (**reflecting**).

Participants reflect on both the vignettes and their own recorded lessons. After the intervention, they film three more lessons, allowing comparisons of teaching quality.

Work assignments, embedded in nested response options (Weiler et al., 2023) accompany the vignettes and are used to assess pv. An expert norm ensures the evaluation is objective. To guide recordings, a script and adapted manual were provided. Due to space limitations, this article focuses on interview findings concerning opportunities and challenges in implementing the intervention. An overview of all preliminary examinations can be seen in Figure 2.

Figure 2.
Preliminary Examinations in order to analyse pv and Teaching Practice.



3. RESULTS

3.1. Code-System–Opportunities and Challenges in dealing with the video vignettes

The main purpose of the interviews was to ensure the feasibility of the vignettes. To ensure consistency in the data analysis, the data material was coded by two coders who had previously agreed on the code definitions. The categories were developed through a hybrid approach.

The main categories represent deductive categories and the subcategories represent inductive categories (see Table 1).

Table 1.
Code definitions of the preliminary interviews (prospective teachers, N = 8).

Category (deductive)	Subcategory (inductive)	Description of Category
Authenticity of the videos	Authenticity of the content	This category includes all statements regarding the authenticity of the video vignettes (acting performance and (technical) content authenticity).
Alternatives to video-vignettes	-	This includes all statements in which alternatives to video vignettes are discussed.
Nested response options	Reflection on decisions	All statements that are mentioned in connection with the nested response options and the action alternatives in vignette format are summarized here.
Key insights from the course	Reflection on one's own actions	This category summarizes all passages in which the respondents make statements about what their main learning from the course was.
Technical handling of the platform		All statements relating to the handling of the platform in which the vignettes are implemented are summarized here.

The inter-coder reliability was calculated on the basis of the code overlaps (50% of the material was recoded) on individual segments with a minimum agreement of 90% and can be stated as good. In the calculations, Kappa was used according to Brennan & Prediger (1981) $\kappa = 0{,}81$. This score can be explained by the good pre-structuring and the joint definition of the category system as well as the iterative discussions and coding process by the two coders. The differences in the coding were analyzed after the comparison and were relatively minor. The main difference in content was the classification into main codes and subcodes. In the following section, the key results regarding the categories will be presented (all citations from the interviews were translated by the authors).

3.2. Authenticity of the video vignettes

Interviewees offered a nuanced view on the authenticity of the video vignettes. While the scripted format was often seen as limiting realism–described as "acted" or "staged," especially in children's dialogue–it was not regarded negatively. Many saw the artificiality as a purposeful didactic reduction that helped focus on key lesson aspects.

Most participants ($N = 8$) acknowledged the scenes felt "not quite real," yet still found them valuable for illustrating core concepts efficiently. As one noted:

"*You realized it was scripted, but I don't think that's a bad thing. It helped get to the heart of the ideas quickly."* (I08, l. 14).

Some students pointed out that knowing the actors (teachers) reduced authenticity. However, this issue is unlikely to affect the actual study, as participants won't know the teachers in the videos. In summary, the scripted nature was perceived critically but also accepted as pedagogically useful and authentic regarding content.

3.3. Alternatives to video-vignettes

Participants generally viewed video vignettes as effective pedagogical tools. A perceived key advantage was their accessibility and time efficiency. As one participant noted, "*It is clearly more convenient for the viewer to observe the content via video rather than having to read everything."* (I08, l. 21). The multimodal format was valued for presenting classroom dynamics more vividly than static text:

"*It is not static text, but an actual video where numerous aspects are presented that one can focus on, which is simply not feasible in textual form.*" (I01, l. 33).

Short, focused clips were praised for effectively illustrating student conceptions without requiring much time:

"*I perceive the advantage in short video sequences rather than employing a text-based format.*" (I08, l. 39).

Some also suggested supplementary methods–e.g., interviews or questionnaires–to enrich understanding, what indicates that the videos encouraged the students to reflect on measuring pupils' conceptions:

"*I could also envisage interviews where children are asked the same questions and actively respond.*" (I09, l. 77).

In sum, video vignettes were seen as engaging, efficient, and authentic learning tools. However, integrating optional formats may accommodate diverse learning preferences.

3.4. Nested response options

A key feature of the branching video vignettes was their ability to offer realistic decision-making options. One participant compared the experience to gaming:

"*It somewhat resembles my computer game […] responding in a manner one might personally choose–[…] more than in linear videos*." (I01, l. 80-83).

Participants appreciated being able to influence how the video unfolded. However, some found it difficult to track and revisit alternative paths without taking notes. After viewing all branches, several participants reported they would have chosen differently in hindsight.

The format also encouraged reflection on teaching choices and the rationale behind them:

"*Why would one select Branch A over Branch B? What are the decisive moments prompting that decision?"* (I01, l. 86)

Seminar discussions revealed differing views on what constituted a "correct" path–some favoring immediate practical engagement, others preferring theory-based input first. While the rewind function was acknowledged as artificial, the branching structure allowed valuable exploration of alternate classroom strategies.

This interactive element was seen as a core strength:

"*It was very clear because one could decide for oneself which path to follow*." (I02, l. 15).

Overall, participants valued the opportunity to compare instructional options and reflect critically on pedagogical decisions. The branching format supported deeper understanding of classroom dynamics and variability.

3.5. Key insights from the course

Another recurring theme within the interviews was the value of self-observation through video and its connection to reflection. One participant explained: *"It really helped me seeing myself teaching. To see what my typical actions are, how I respond to questions, how I interact with students."* (I01, l. 24-25). This kind of reflective practice was often described as leading to greater awareness and a more deliberate approach to teaching. As one interviewee put it, *"You're actually confronted with your own teaching processes and thought patterns, and that makes you rethink them."* (I06, l. 15-17).

In this context, the interviews suggest that video-based self-observation can enhance professionalisation processes by fostering critical reflection. It allowed the prospective teachers not only to reflect on their own practices but also to recognize that there are multiple ways to approach classroom situations: *"You reflect on your own teaching, but you also see how many different ways there are to do things."* (I06, l. 21-22).

Furthermore, participants described the recognition of their own learning needs and the development of a more nuanced view of their pupils as key takeaways. The reflective process was not limited to subject-specific methods but extended to relational and communicative dimensions of teaching.

3.6. Technical handling of the platform

Participants frequently mentioned difficulties in navigating the vignette platform, especially at the beginning. The interface was described as unintuitive and confusing:

"*At the beginning, you feel like you don't know where to click, or where to answer.*" (I05, l. 126).

"*Sometimes I clicked further even though I shouldn't have […] I wasn't very satisfied with the platform.*" (I04, l. 66-67).

A key issue was the misalignment between video content and follow-up questions. Learners often didn't know what to focus on:

"*It would've helped to see the questions while watching the video […] I was focusing on something completely different."* (I09, l. 62-63).

Participants suggested improvements such as structural overviews:

"*A diagram showing how the strands connect […] so you can check off what you've already watched.*" (I01, l. 139-140).

An onboarding or tutorial vignette was also proposed: "*Maybe the instructor could do a short walkthrough at the start […] before the real content begins*." (I05, l. 128-129).

In sum, the interviews highlight the need for clearer guidance and technical scaffolding to support effective use of video vignettes in teacher education.

4. DISCUSSION

The present findings indicate considerable potential for video-based interventions to enhance the professionalisation of career changers in STEAM education. Although some participants in the preliminary phase perceived the scripted nature of the vignettes as less realistic, the structured design nonetheless facilitated targeted learning and systematic reflection. Particularly noteworthy was the opportunity to compare instructional decisions within the branching video format and to engage actively with pedagogical dilemmas in a controlled environment. Nevertheless, several limitations must be acknowledged. The preliminary results are based on a small, context-specific sample, which constrains the generalisability of the findings. Familiarity with some of the actors in the vignettes may have influenced perceptions of authenticity. Technical challenges related to platform navigation and the alignment of video content with subsequent questions may also have

affected participants' engagement. The next phase of the ongoing study will directly address these aspects. Planned refinements to the technical platform - such as onboarding tutorials and improved navigation - are designed to enhance both usability and learning efficiency. Some of these improvements have already been implemented, including the collective discussion of pupils' conceptions of robotics during training and the provision of clearer technical guidance. In addition to expanding the sample to include career changers, out-of-field teachers, and subject-qualified teachers from multiple Austrian federal states, the study will examine whether enhancements in pv lead to sustained changes in classroom practice, thereby clarifying the link between pv and professional action. To achieve this, the study will incorporate video recordings of participants' lessons, allowing for a direct evaluation of professional teaching practice. The ongoing large-scale implementation is therefore positioned not only to test the effectiveness of the approach in a broader context but also to generate evidence-based recommendations for the professionalisation of career changers in STEAM education.

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Measuring Indoor Air Quality - A Citizen Science Approach for Authentic STEM-Teaching

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Abstract

The indoor air quality in schools affects the wellbeing, concentration, and performance of pupils (Wargocki, 2015). International studies show that CO_2 concentrations in classrooms often exceed the recommended reference value of 1000 ppm (Dorizas et al., 2015; Stabile et al., 2016). To address this issue, a citizen science approach was chosen. The DIGIdat project aims to improve indoor air quality. Specifically, measurements were conducted, and the effectiveness of various interventions was empirically tested (Beck et al., 2023; Krois, Hechenberger & Goreth, 2023). Pupils were actively involved in the research process from the outset. The *DIGIdat* project focused on the parameters: CO_2 concentration, fine dust pollution, temperature, and humidity. The research design includes quantitative data from measurements in classrooms (N = 36 with 150 sensor kits in 10 school locations and continuous testing) and a quantitative online survey with pupils (N = 1792 data sets with 614 pupils, repeated surveys) at the school sites. To make the assessments more comprehensive, subjective evaluations were compared with objective measurements, and relationships with gender- and age-specific differences, technology socialization, and seating position were also examined.

The results show that classes with window ventilation have higher concentrations of CO_2 and PM2.5, which was confirmed to be statistically significant. Humidity levels were also statistically significantly lower in mechanically ventilated classrooms. With window ventilation, a correlation between the CO_2 values and the outside temperature was observed. In general, the colder the outside temperature, the higher the CO_2 concentrations, often exceeding 2000 ppm. Furthermore, the students' subjective perceptions of temperatures within and above the recommended range (20–24 °C) corresponded closely with the measured values and technical recommendations. These research results provide a basis for formulating concrete guidelines for public school authorities. In addition, they support the development of motivating STEM lessons that can subsequently be transferred to other school settings.

Key Words: Citizen science approach, STEM-Teaching, Indoor air quality, Digital technology and production processes

1. INTRODUCTION

Indoor air quality (IAQ) in schools plays a critical role in shaping pupils' health, concentration, and despite its importance, classrooms in many countries continue to suffer from poor IAQ due to insufficient ventilation and limited awareness. The COVID-19 pandemic has further highlighted the need to better understand and improve indoor environmental conditions, particularly in educational settings where children spend a significant portion of their day. Improving IAQ requires more than technical solutions; it also demands educational strategies that actively involve learners. Citizen science offers a promising approach in this regard. By engaging pupils in authentic research processes - such as data collection, environmental monitoring, and result interpretation - pupils become co-investigators, gaining hands-on experience in STEM and contributing meaningfully to real-world problem-solving.

This paper presents the results of the *DIGIdat* project, which applies a citizen science framework to investigate IAQ in Austrian classrooms. The project combines objective sensor-based measurements of CO_2, fine dust pollution, temperature, and humidity with pupils' subjective evaluations of the indoor climate. By comparing measured data with student perceptions, the study provides insights into the effectiveness of different ventilation strategies and demonstrates how STEM education can be both participatory and relevant.

1.1. Indoor air quality in schools

The COVID-19 pandemic has increasingly brought the issue of indoor air quality in schools to the forefront of public attention. An examination of the daily lives of school-aged children and adolescents reveals that they spend the majority of their time indoors, whether at home or in school buildings. However, classroom air quality is frequently suboptimal, a fact supported by numerous studies. In the Austrian *Luft-Kinder-Studie* (Hohenblum et al., 2008), for instance, CO_2 concentrations were analysed across several classrooms. The moving hourly average of CO_2 levels exceeded the threshold set by the Austrian guideline for assessing indoor air quality in schools in 16 out of 18 classes (Tappler et al., 2017).

To assess indoor air quality, CO_2 concentration is commonly used as a proxy indicator for gaseous pollutants, alongside measurements of fine dust (Persily, 1997). In classrooms—defined as indoor spaces designed for the continuous presence of individuals engaged in cognitive activities—CO_2 concentrations should not exceed 1000 ppm, with ideal levels remaining below 800 ppm. Studies conducted in other countries also confirm the widespread issue of poor indoor air quality in classrooms. In many of the schools examined, average CO_2 concentrations significantly exceed the 1000 ppm threshold over extended periods (Corsi et al., 2002; De Giuli et al., 2012; Dorizas et al., 2015; Stabile et al., 2016; Toftum et al., 2015; Yang et al., 2009). In the study by Hohenblum et al. (2008), peak CO_2 values frequently exceeded 2000 ppm. This poor air quality is often attributable to inadequate ventilation and insufficient exchange of indoor air. For children and adolescents aged between 6 and 19 years, a minimum outdoor air supply of 25 to 33 m^3/h per person is recommended (Greml et al., 2021). In the case of secondary school pupils aged between 10 and 14, a minimum of 32 m^3/h should be provided. However, a deficiency in indoor air quality is not always readily perceived by the human nose; for instance, at 2000 ppm only approximately 40 % of individuals report dissatisfaction, rising to just over 50 % at 3000 ppm.

Nonetheless, indoor air quality has a demonstrable impact on the learning capacity and academic performance of children and adolescents. Wargocki (2015) provides a comprehensive summary of various studies addressing this issue and highlights their key findings. A correlation between indoor air quality and pupils' learning ability can be clearly established. Doubling the rate of fresh air exchange in classrooms has been shown to improve pupils' performance by up to 14%. Analysis of various studies further indicates that increasing the supply of fresh air by 1 litre per second (equivalent to 3.6 m^3/h) per person can lead to improvements in schoolwork outcomes and a reduction in pupil absenteeism.

A typical CO_2 concentration curve for a fully occupied classroom demonstrates that, in addition to interactions with temperature and relative humidity, recommended threshold values are frequently exceeded. In many cases, elevated CO_2 levels are already present at the beginning of the school day.

1.2. Citizen science approach

A citizen science research approach involving pupils can be adopted to address the challenges outlined above (Kullenberg & Kasperowski, 2016). This approach allows young people to actively participate in genuine scientific projects and to engage directly with research processes. For example, pupils collaborate with scientists to collect data, observe phenomena, or formulate their own research questions. Such participatory engagement not only fosters interest in science, technology, and research, but also strengthens key competencies such as critical thinking, collaboration, and scientific literacy. Simultaneously, researchers benefit from the involvement of motivated school classes, particularly in large-scale data collection efforts. This collaboration helps to establish a valuable link between schools and the scientific community (Haklay, 2013; Bonney, 2009).

In line with with this approach, the *DIGIdat* project placed pupils at the centre of the research process, assigning them the role of Young Scientists (YS). The project is coordinated by two university institutions: the University of Education Tyrol and the University of Innsbruck. In addition to pupils, other citizen scientists are also integrated into the research process, including:

- Architects
- Technicians and civil engineers
- Medical professionals
- Members of a civic initiative
- Building owners

Over the period of the three-year project, approximately 750 pupils from 10 classes of around 25 pupils each at schools in Tyrol are directly involved. These pupils support additional classes at their respective school sites in collecting measurement and survey data—across at least three classes per location—and collaboratively implement improvement measures. In total, around 2,250 pupils will thus be indirectly engaged in the project, raising broader awareness of the issue of indoor air quality.

In addition to raising awareness of air quality in school buildings, the Young Scientists address the following key topics within the project:

- Healthy and comfortable indoor environments
- Energy-efficient and sustainable building practices, including Education for Sustainable Development
- Measurement and control technologies (e.g. for indoor air quality, temperature, and humidity)
- Design and fabrication of measurement boxes
- Digital methods for data transfer, transmission, and management (e.g. IoT devices)
- Social science methodologies (e.g. surveys on subjective perception)
- Scientific approaches to empirical research
- Scientific communication, including the presentation and discussion of results
- Direct engagement with, and insights into various technical and scientific professions

At the core of the project are the expert phases, which include workshops, as well as supplementary project meetings and networking exchanges with the citizen scientists during the active working phases. The initial project meeting served as a framework-setting event, during which all participating citizen scientists were introduced to one another and had the opportunity to network. The school workshops were designed so that no prior technical knowledge—such as programming—is required from participating teachers. These workshops are delivered by the project staff from the coordinating universities. In developing the workshop phases, which provide an introduction to the various thematic areas, the citizen scientists worked in close collaboration with the project staff to ensure both content alignment and practical relevance.

2. METHODOLOGY

2.1. Research Questions

Indoor air quality in schools is a critical factor influencing the health, concentration, and overall well-being of both pupils and teachers. In Austria, the question arises of how current conditions in classrooms should be evaluated with respect to air pollutants and CO_2 concentrations. Both geographical location and day-to-day ventilation practices play a significant role in this context. Alongside objectively measurable parameters, the subjective perception of indoor air quality is receiving increasing attention—particularly regarding whether and how technical measures deliver not only objective improvements but also perceived benefits.

The following research questions emerge from these considerations:

RQ1: What is the current state of indoor air quality in Austrian schools?

RQ1.1: What are the levels of fine dust and CO_2 concentrations in classrooms, particularly in relation to factors such as location, building condition, and ventilation behaviour?

RQ1.2: How effective are technical interventions (e.g. mechanical ventilation systems, air purifiers)?

RQ2: To what extent does pupils' subjective perception of air quality differ from the technically measured values?

RQ2.1: Which aspects of the learning environment that support effective learning can be identified?

RQ2.2: Can improvements in indoor air quality also positively influence pupils' subjective perceptions?

These research questions form the foundation of the investigations presented here, which combine technical measurement data with perceptual surveys in order to develop evidence-based recommendations for everyday school practice.

2.2. Sample, Data collection and instrumentation

To collect indoor climate data, specially developed environmental monitoring stations based on the senseBox Do-It-Yourself kit (Institute for Geoinformatics, 2023) were employed. Each station comprises a microcontroller, sensors for CO_2, fine dust, temperature, brightness, and sound, as well as a WiFi module and an SD card. The sensors record data at five-second intervals, storing the measurements on the SD card while simultaneously transmitting them in real time to the OpenSenseMap platform.

For calibration, the CO_2 sensor was set to 1014 ppm using calibration gas and adjusted to account for the altitude of Innsbruck. Temperature readings were found to be systematically approximately 1°C too high; this discrepancy was considered during data analysis. The remaining sensors were calibrated using appropriate reference instruments.

In each classroom, pupils installed three sensor boxes arranged diagonally to facilitate a representative assessment of indoor air quality. The project team subsequently verified the installations and made adjustments where necessary.

Over the three-year project period (November 2022 to June 2025), more than $N > 1.2$ billion data points were collected across $N = 36$ classrooms, utilising 150 sensor kits in 10 schools, and involving approximately 750 pupils.

To capture the subjective perception of the indoor climate, an online questionnaire was developed using *SoSciSurvey*. Pupils provided a personal identifier, enabling their responses to be anonymously linked to the corresponding measurement times. The university's ethical guidelines for handling student data were fully observed. The questionnaire comprised items designed by an interdisciplinary team of four experts within the *DIGIdat* project, employing a five-point Likert scale. These items addressed:

- Perceptions of indoor climate parameters—including temperature, smell, brightness, and volume (three items per parameter; for example, "I find the temperature pleasant.")

- General questions relating to overall perception, learning conduciveness, and personal relevance (eleven items; for example, “How important are the following aspects for your learning?”)

In addition, socio-demographic data and aspects of technological socialisation were collected, based on items from the Acatech/VDI-Nachwuchsbarometer (2009) and personality traits (e.g., Gerlitz & Schupp, 2005), which are not further discussed in this article.

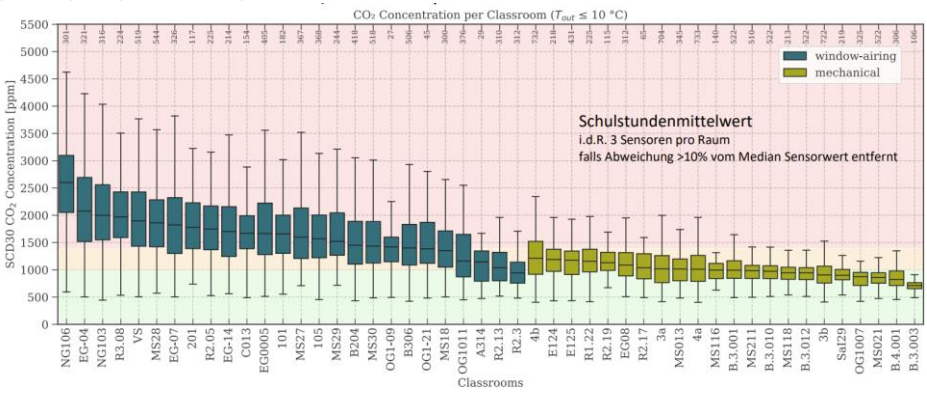
A total of N = 1792 data sets were gathered, comprising responses from 614 students through multiple surveys. The sample consisted of 42.4 % *female*, 55.6 % *male*, and 1.9 % *diverse* students. The majority of participants were aged *between 12 and 14 years* (70.6 %), with 10.4 % aged *11 or younger*, and 19 % aged *15 or older*.

3. RESULTS

3.1. Comparison of CO_2 Concentrations in Classrooms with Window Ventilation and Mechanical Ventilation

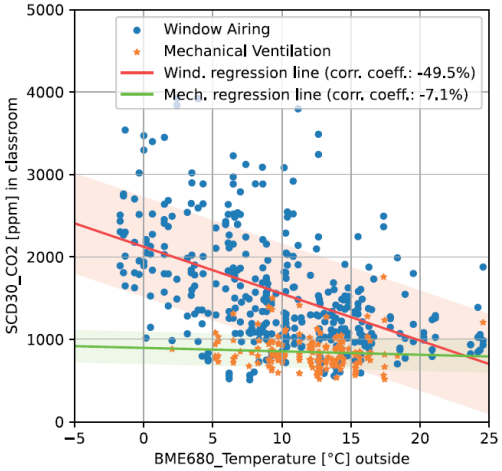
The following figure (Fig. 1) illustrates that classrooms ventilated by windows perform worse in terms of CO_2 concentration compared to those equipped with mechanical ventilation systems. The boxplots display CO_2 measurements according to the type of ventilation: *mechanical ventilation* (green) and *window ventilation* (blue). Classrooms relying on window ventilation exhibit a wider range of CO_2 values than those with mechanical systems. The results indicate that CO_2 levels are significantly higher in window-ventilated classrooms. Statistical significance was determined at the 5 % level (CO_2 concentrations: window ventilation > mechanical ventilation, Mann–Whitney U test, $p < 0.01$ %, highly significant; PM2.5 concentrations: window ventilation > mechanical ventilation, Mann–Whitney U test, $p < 0.05$, significant).

Figure 1.
CO_2 concentration comparison between window and mechanical ventilation during the cold season (≤ 10 °C) – 1 (DIGdat, 2025)



The correlation between indoor and outdoor values was analysed using data pairs averaged over a three-hour period (9 a.m. to 12 p.m.). The results demonstrate a strong association between outdoor temperature and CO_2 concentrations in classrooms with window ventilation, whereas this relationship is negligible in mechanically ventilated classrooms. This suggests that lower outdoor temperatures reduce manual ventilation, while mechanical ventilation systems with heat recovery remain largely unaffected.

Figure 2.
CO_2 concentration comparison between window and mechanical ventilation – 2 (Beck et al., 2023)

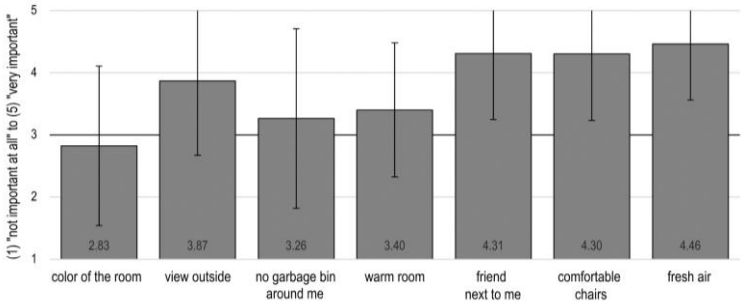


The CO_2 concentration decreases markedly with rising outdoor temperature in classrooms *ventilated by windows* (correlation coefficient = –49.5 %), whereas the decrease is less pronounced in *mechanically ventilated* classrooms (correlation coefficient = –7.1 %). When the outside air temperature exceeds 20 °C, CO_2 concentrations in classrooms remain below the recommended guideline values for both ventilation types.

3.2. Perception of Indoor Air Quality

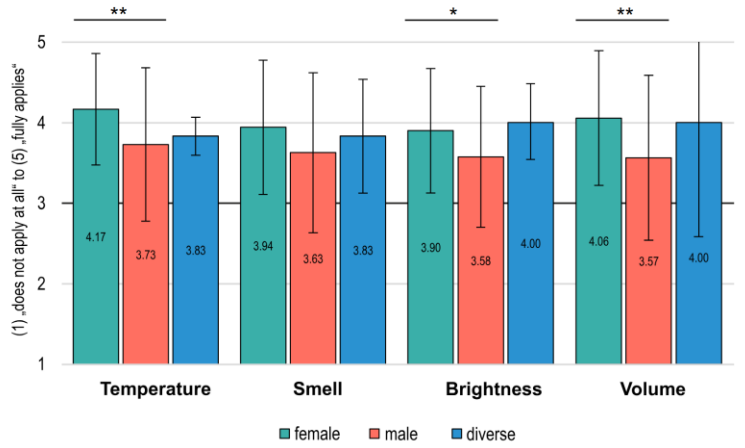
The following figure illustrates aspects relevant to learning. Pupils consider factors such as the *colour of the classroom* (M = 2.83; SD = 1.28) or the *proximity of the rubbish bin* (M = 3.26; SD = 1.19) to be less important for their learning compared to being *near friends* (M = 4.31; SD = 1.06), having *comfortable chairs* (M = 4.30; SD = 1.07), or having access to *fresh air* (M = 4.46; SD = 0.90).

Figure 3.
Aspects of learning



The pupils' perception focuses not only on aspects of social interaction or classroom furnishings, but also strongly on the room climate and its impact on their learning performance.

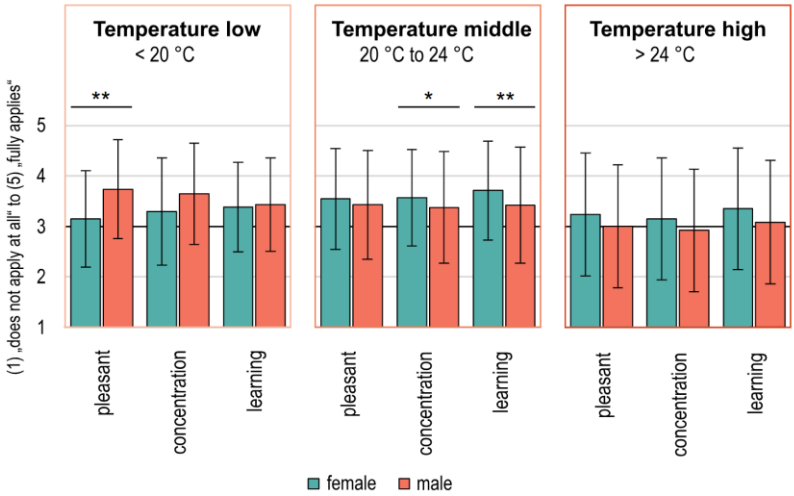
Figure 4.
Importance of the room parameters by gender



The students exhibit minimal differences in their overall perception of various aspects of the indoor climate; however, distinctions become evident when comparing responses across different genders. *Female* pupils rate *temperature* as more important (M = 4.17; SD = 0.69) than *male* pupils (M = 3.73; SD = 0.95; $p < 0.01$). Both *female* and *diverse* pupils perceive *brightness* (female: M = 3.90; SD = 0.77; *diverse*: M = 4.00; SD = 0.47; $p < 0.05$) and *volume* (*female*: M = 4.06; SD = 0.84; *diverse*: M = 4.00; SD = 1,41; $p < 0.01$) as more significant than *male* pupils do (*brightness*: M = 3.57; SD = 0.87; *volume*: M = 3.57; SD = 1.02). Differences in the perception of *smell*, however, were not statistically significant.

Figure 5 illustrates that male students tend to benefit more from lower temperatures, which are perceived as more *pleasant* (M = 3.74; SD = 0.98) compared to female pupils (M = 3.15; SD = 0.96; $p < 0.01$). Additionally, lower temperatures are regarded as more important for concentration by male students (M = 3,65; SD = 1.01) than by female students (M = 3.29; SD = 1.06). However, this pattern changes at higher temperatures. When temperatures exceed 24 °C, *concentration* and *learning* tend to decline for both gender groups, with no statistically significant difference observed. At moderate temperatures (between 20 °C and 24 °C), female students report higher perceived *concentration* and *learning* ($M_{concentration}$ = 3.57; SD = 0.96; $M_{learning}$ = 3.71; SD = 0.98) compared to male students ($M_{concentration}$ = 3.38; SD = 1.08; $p < 0.05$; $M_{learning}$ = 3.42; SD = 1.15; $p < 0.01$).

Figure 5.
Temperature perception by gender



4. DISCUSSION

The findings of the present project clearly demonstrate the need to improve indoor air quality in school buildings. Window ventilation, in particular, proves to be significantly less effective than mechanical ventilation; CO_2 and fine dust concentrations are considerably higher in window-ventilated classrooms, especially during periods of low outdoor temperatures. This underscores a clear need for action—both in terms of infrastructural provision and everyday pedagogical practice.

A key finding is the consistently high level of CO_2 concentrations in many classrooms, often exceeding recommended guideline values. The correlation between indoor air quality and pupils' performance is well established in the scientific literature: poor air quality impairs both

concentration and performance. The results of this project reaffirm these associations. In particular, the demonstrated reduction in CO_2 concentrations through technical interventions—such as the use of mechanical ventilation systems—emphasizes the urgent need for structural improvements in school environments.

Another key aspect of this study is the integration of objective measurements with pupils' subjective perceptions. This approach is particularly innovative, as it not only highlights potential avenues for technical optimisation, but also provides insight into how such changes are experienced by those affected. The findings reveal that pupils subjectively perceive lower CO_2 concentrations as indicative of more pleasant indoor air. The data further confirm that pupils' perceptions of indoor air quality—particularly regarding temperature—align closely with scientific recommendations.

Notably, gender-specific differences emerge: male pupils tend to rate lower temperatures more positively and perceive them as more conducive to concentration than their female counterparts. This is a potentially important consideration for the design of learning environments and the regulation of heating systems in schools. The workshops implemented within the project, following a citizen science approach, demonstrate how interdisciplinary, hands-on STEM education can be effectively delivered. Pupils not only develop awareness of the importance of a healthy indoor climate, but also acquire foundational knowledge in physics, technology, biology, and computer science—an integrative and exemplary educational model. Furthermore, these findings carry significant pedagogical implications: engaging pupils directly in monitoring and understanding their indoor environment fosters active learning, critical thinking, and a sense of responsibility for their own well-being. However, the scalability of such citizen science approaches is limited by available resources, teacher training, and the variability of school infrastructures.

The findings of this study may serve as a foundation for concrete measures aimed at school authorities and education policymakers. In the long term, mechanical ventilation systems with heat recovery should be established as standard in school buildings. In the short term, low-threshold educational initiatives are needed to raise awareness of improved ventilation practices among teachers and pupils.

A noteworthy secondary observation is that air quality is often already poor at the beginning of lessons. This suggests that elevated CO_2 levels do not only accumulate during the school day but may also result from prior use of the rooms or insufficient night-time ventilation. Accordingly, optimization of ventilation strategies should take these factors into account. Furthermore, the architectural features of school buildings—such as ceiling height, window area, and thermal properties—should receive greater attention in future studies.

It must be acknowledged as a limitation that the results pertain exclusively to schools in Tyrol (Austria). Technical challenges encountered during data collection—such as the systematic deviation in temperature readings and the need for CO_2 sensor calibration—were transparently reported within the project. This, however, contributes to scientific transparency and highlights to pupils that research inherently involves uncertainties and technical constraints.

For further research, it would be desirable to extend the project beyond Tyrol to other federal states or even internationally. A comparison of different types of schools, building standards or climatic conditions could provide additional insights. Long-term monitoring after the implementation of technical measures (e.g., installation of ventilation systems) would also be useful to evaluate their effectiveness not only in the short term but also in the long term.

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Integrating Computational Thinking and the Writing Process in Primary School

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Abstract

In today's rapidly evolving world, computational thinking and writing are foundational skills with broad applications across disciplines. We propose a qualitative study that investigates how primary school teachers can integrate computational thinking concepts—such as abstraction, decomposition, algorithmic thinking, and debugging—with key steps of writing process including planning, sequencing, crafting, and editing text. The integration aims to enhance teachers' knowledge and skills in both disciplines through activities and ideas grounded in local and authentic contexts. It aligns with the refreshed New Zealand Curriculum, which emphasizes Mātaiahikā—connecting to place and community—and promotes the importance of contextually relevant teaching that builds on local knowledge while strengthening literacy and numeracy.

In partnership with a small-town school in New Zealand's North Island, this study investigates how collaboratively developed unit plans can integrate these two skills sets effectively—enhancing curriculum delivery while reducing additional demands on classroom time and maximizing the advantages of cross-disciplinary teaching. By situating teaching practices in authentic, interdisciplinary contexts, this study seeks to support and deepen teachers' understanding of the overlapping concepts in writing and computational thinking and develops practical strategies that improve engagement and learning outcomes by making connections between designing code and crafting text.

Preliminary findings suggest that such integration can be particularly impactful for student engagement. For instance, a 10-year-old boy likened debugging his app code to editing his writing, stating it was "like editing... but way cooler!" This anecdote highlights the potential of this approach to resonate with students, especially boys who might struggle with writing, and girls who may feel less connected to computational tasks. Ultimately, the study aspires to inform teacher practice and improve educational outcomes by illustrating how linked processes in writing and computational thinking can provide mutual reinforcement, thereby empowering students with versatile, transferable skills and a deeper appreciation for interdisciplinary learning.

***Keywords**: computational thinking, digital technologies, technology education, writing education, primary, authentic technology practice*

1. INTRODUCTION

Computational thinking (CT) is a vital skill for problem-solving in the digital age, helping individuals approach complex tasks in a logical and efficient way. It empowers learners to break down problems, identify patterns, and create solutions that can be implemented by both humans and machines. Computational thinking includes algorithmic thinking, abstraction, decomposition, debugging, and generalising information. Such skills can be applied in the realm of technology education and used in everyday life. Introducing CT to young children is an excellent way to provide children with a strong computational and digital foundation for future success in designing, developing and participating in a rapidly changing technological world. At the same time writing is an area of significant learning for students throughout their years in school. Writing impacts personal and professional opportunities and outcomes beyond school (Graham, 2020) and it supports students' academic success (Graham, 2020; Koster et al., 2015; Myhill & Chen, 2020). Writing is used across disciplines to present evidence of learning and as a tool for developing and deepening learning (Graham, 2020). This study embraces the interdisciplinary integration of computational thinking and writing to enhance teachers' teaching and students' knowledge and skills in both disciplines. In line with the New Zealand Curriculum refresh project, which embraces Mātaiahikā—a commitment to connecting learning to place and community—the study will focus on middle primary students working within an authentic, real-world context to support the development of literacy- and numeracy-rich curricula grounded in the local environment.

This paper reports on a proposed study that involves collaboration with the principal, teachers, and students at a low-decile, small-town school in the North Island of New Zealand. The research team—comprising a computer scientist, a teacher educator, and a summer scholar—will (1) explore the connections between key computational thinking (CT) concepts (abstraction, decomposition, algorithmic thinking, and debugging) and core process writing skills (planning, sequencing, crafting, and editing), and (2) develop integrated teaching strategies that draw on overlapping concepts in computational thinking and writing. Learning units will be designed to promote knowledge transfer, allowing students to revisit and reinforce ideas in ways that are mutually supportive across both domains. Students will develop their computational thinking and skills by drawing on key ideas from writing, while also motivating them to write and edit their writing through engagement with our digital tool (Kete) that promotes computational thinking. This interdisciplinary approach will enable both teachers and students to deepen their understanding and broaden their capabilities by transferring skills between writing and CT processes.

2. LITERATURE REVIEW

What is Computational Thinking

Computational thinking synonymously known as "21st century literacy" (Grover & Pea, 2013, p. 40) or as the skill set of the 21st century (Mohaghegh & McCauley, 2016) has been at the forefront of educational and professional discussions in recent years due to its undeniable relevance and importance as a critical skill for thriving in the 21st-century world. It is recognized as a fundamental competency that equips individuals with the ability to analyse complex problems, think logically, and devise effective solutions using computational processes (Wing, 2006) According to Wing computational thinking is not confined to the realm of computer science or computational studies; rather, it extends its applicability to a wide array of disciplines, including literacy, numeracy, reading, and writing. This universality makes CT an essential tool for fostering interdisciplinary learning and problem-solving. Hence, it has become a powerful analytical tool to be learnt in the classrooms. Computational thinking is described as a "thought process" (Aho, 2012, p. 1) in understanding and attempting to find a solution to a complex problem using computational processes like abstraction, sequencing, decomposition, pattern recognition, parallel thinking and debugging. (Grover & Pea, 2013; Wing, 2006). Riley and Hunt (2014) suggests it is "the way that computer scientists think, the manner in which they reason" (p. 4). CT is a cognitive skill that needs to be developed for effective problem solving. Interestingly, Duncan et al. (2017) argue that these concepts of problem solving and thinking processes exists outside the world of computing and many describe CT as a skill that exists with many other disciplines.

The Process of Writing

"Writing well is not just an option for young people, it is a necessity" (Graham & Perin, 2007, p. 3). Hence, teaching writing involves careful guidance of young learners through a systematic process to help them develop foundational skills in writing and composition. Writing is not only an essential academic skill but also a means of fostering creativity, critical thinking, and communication. In primary classrooms, students often engage in writing tasks such as essays or descriptive pieces, which follow a structured process. This process typically includes prewriting, drafting, revising, editing, and publishing (Cavkaytar & Yasar, 2010; Graham & Perin, 2007). In addition, there can be other elements to writing such as, summarising, collaborative writing, specific product goals, inquiry activities, study of models (Graham & Perin, 2007). All these stages altogether formulate a set of process in which students can develop their writing skills in a more systematic and a methodical way. To create a written piece of work, students need to take a step-by-step approach rather than attacking it as a whole. That way they get to plan content, minimise the errors and most importantly to create a beautiful piece of work.

Computational Thinking Integrated with Writing

Computational thinking methods can be applied across a range of disciplines to develop effective solutions (Wing, 2006). Bell and Lodi (2019) emphasise the importance of embedding CT into real-world applications including writing, to help students see its relevance. For instance, writing algorithms can scaffold tasks like sentence construction, story mapping, and editing. In primary

education, where foundational skills are built, integrating CT into writing instruction has the potential to foster critical thinking, enhance creativity and improve the overall quality of the piece of writing.

Writing and computational thinking share commonalities in process, orientation and systematic problem-solving. Writing involves multiple stages, including brainstorming, drafting, revising, and editing, all of which can benefit from CT principles (Karen Brennan & Mitchel Resnick, 2012). The following shows practical mapping between computational thinking (CT) and the writing process, showing how each CT skill parallels steps in planning and producing a piece of writing in primary school writing:

Computational Thinking Concept	**Writing Process Equivalent**	**Explanation / Example**
Decomposition	Prewriting/ Brainstorming	Break the writing task into smaller parts (e.g., introduction, body paragraphs, conclusion) just like breaking a problem into manageable steps.
Pattern Recognition	Outlining	Recognize structure/themes or common linguistic features in different texts (e.g., persuasive essays often follow a similar format). Helps in structuring your own piece.
Abstraction	Main ideas	Focus on the essential ideas and remove unnecessary details. Like summarizing the core message of a paragraph or argument.
Algorithmic Thinking	Drafting Organizing	Follow a logical sequence to organize ideas clearly (e.g., topic sentence → evidence → analysis). Similar to designing step-by-step instructions.
Evaluation Debugging	Editing / Revising	Review and fix issues like grammar, clarity, flow—similar to testing and correcting code.

Decomposition involves breaking big, complicated tasks or systems into smaller, manageable parts and helps students approach writing tasks methodically. Writing an essay, for instance, can be overwhelming for primary school students. Using the decomposition method in CT, students separate different parts of a problem to focus on one aspect at a time without getting overwhelmed (Wing, 2006). For example, young learners can be taught to break a narrative into components such as setting, characters, conflict, and resolution, or break an argumentative essay down into smaller tasks, such as writing an introduction, developing main points, and crafting a conclusion.

Pattern recognition aids students in critical thinking, problem-solving and mathematical understanding. As the name suggests, it involves identifying similarities, trends, and regularities within data or problems. In primary education, this skill significantly enhances writing abilities by helping students recognize and apply structural and linguistic patterns, thereby improving their reading comprehension and writing proficiency (Learning.com., 2023). For example, pattern recognition enables young writers to identify common structures in well-structured stories and then use the structure to organize their thoughts coherently (Reading Rockets, n.d.). Additionally, understanding patterns in sentence construction and grammar helps students form correct and varied sentences, enhancing the readability of their writing. By emphasizing pattern recognition in writing, educators can provide students with tools to approach writing tasks methodically,

leading to improved writing outcomes and a deeper understanding of language structures (Learning.com., 2023).

Abstraction involves filtering out irrelevant details to focus on the core idea, identifying patterns that are not relevant to solve the problem and enabling a focus on only the important data without getting distracted by irrelevant data (BBC Bitesize, n.d.). In writing, this skill in writing is vital for summarizing texts, synthesizing information, and crafting concise thesis statements. For primary school students, abstraction can be introduced through activities like summarizing stories or identifying the main idea in a passage. This practice not only enhances comprehension but also equips students with the ability to distil their thoughts and present them clearly.

Algorithmic thinking entails creating step-by-step instructions or a process to solve a problem or achieve a goal (Learning.com., 2023). In writing, this translates to planning and organizing content logically. Primary school students benefit from explicit instruction in structuring their writing, such as using graphic organizers or flowcharts to outline their ideas before drafting. This structured approach reduces cognitive load and helps students focus on developing their arguments. Studies have shown that providing young learners with clear frameworks enhances their writing quality and confidence (Graham & Perin, 2007). Therefore, developing algorithmic thinking can benefit primary students to develop an explicit, well-planned method to writing.

Debugging in writing refers to the editing process of identifying and fixing errors, inconsistencies, or issues in a written text to improve its clarity, coherence, and effectiveness. Like debugging in programming, this involves reviewing and revising the text to eliminate problems such as grammatical errors, logical inconsistencies, poor organization, or unclear arguments. Debugging ensures that the writing achieves its intended purpose and communicates effectively to its audience. These written errors can be fixed by proofreading, revising and getting feedback.

Computational Thinking Integration Methods

The computational concepts of decomposition, pattern recognition, abstraction and algorithms can be easily merged with writing instruction in primary schools, where students are still learning to structure their thoughts and ideas cohesively. The integration can be achieved through computational practice, which share many commonalities with writing process. What is computational practice? It refers to the methods used by computer programmers to solve problems, focusing on the process of thinking and learning—going a step beyond just 'what' you are learning to include 'how' you are learning it (Karen Brennan & Mitchel Resnick, 2012). Both programming and writing require anticipating and understanding problems, abstracting ideas, breaking tasks into modules, and applying skills such as reusing, remixing, debugging, and testing—all of which are central to computational practice. These steps ensure that the final product, whether a piece of writing or a computer program, is functional, coherent, and effective. One core element of computational perspective is its ability of expression and a way of connecting with others in creative ways other than just words (Karen Brennan & Mitchel Resnick, 2012).

Another method of embedding CT into classroom programmes is Computational Thinking Integration Model (CTIM) proposed by Azeka & Yadav's (2021). It primarily focuses on science

and mathematics streams but can be adapted to writing as the steps involved have a resemblance to what teachers already do in the classroom. The first step of the CTIM is guiding students to learn and experience CT without the actual use of computers, with the students learning to think like a programmer (Azeka & Yadav, 2021). In the writing process, this can be achieved by using skills of decomposition, debugging and sequencing. In fact, this first stage of the CTIM model zooms in on students' ability to think in computing and incorporate ideas of CT with other learning. The second step involves computational "tools" like visual data, which can be used in writing processes, especially in descriptive writing in primary schools. The third stage, Computational Inquiry, can be considered the ultimate use of computer tools to actually write a program. It is also the use of these tools to "understand disciplinary phenomena" (Azeka & Yadav, 2021, p. 51). Even though the CTIM model was formed with STEM education in mind, there are parts that can be used to model a writing process within the classroom for teachers.

Pedagogical benefits and challenges of Integrating Computational Thinking and Writing

The intersection of computational thinking and writing has gained traction through New Zealand's curriculum initiatives. Incorporating CT in writing can be a game changer for students as well as teachers as it can bring about so many benefits with it. The integration of CT into writing tasks does not merely enhance technical aptitude; it also enriches students' capacity to think critically, express ideas coherently, and engage with content creatively, thereby preparing them for future academic and professional challenges. Parsazadeh et al. (2021) discuss how CT principles enhance creativity in writing while ensuring logical coherence. Their studies highlight the role of computational tools and activities such as flowcharts, collaborative software, and storyboarding in fostering algorithmic thinking in storytelling. Another prominent advantages of introducing CT in writing is that it can improve the higher-order thinking skills that strengthens students' analytical capabilities and supports critical evaluation, problem-solving, and the ability to organize complex ideas in coherent and structured ways—skills that are essential for both academic success and real-world communication (Wu et al., 2024).

With all the benefits, there are some critical challenges associated with bringing CT into the primary classrooms. One of the challenges is ensuring teachers have the necessary skills and confidence. Yadav et al. (2016) underscore the importance of professional development in equipping educators with strategies to blend CT into literacy instruction. Their findings reveal that workshops and resources focused on computational storytelling improve teacher efficiency and student outcomes. In addition, Irons and Hartnett (2021), identified a disconnection between the government policy, school management and the classroom teachers in bringing in the CT to the classroom. Duncan et al. (2017) identified that CT's abstract nature as potentially intimidating for younger students unless adequately scaffolded. They suggest that gamified approaches and visual tools can mitigate this issue by making CT more relatable. Teacher resistance, stemming from limited understanding or training in computing, is another challenge (Yadav et al., 2016). Overcoming this requires ongoing support, professional learning communities, and resource sharing. Irons and Hartnett (2021) suggest professional development for teachers, introducing a suitable assessment system as well as school wide support to teachers as key factors in addressing this issue. Teacher education programmes could integrate CT into broader literacy approaches. For example, using unplugged activities like paper-based algorithms and collaborative story structuring can make CT more accessible in writing classes.

3. METHODOLOGY

Situated within an interpretive paradigm and based on a socially constructed ontology (constructivism), the study's underlying epistemology will recognise multiple realities and the importance of the researchers' understanding of situations through the lenses of the research participants (Cohen et al., 2018). Brennan and Resnick's (2012) computational concepts model and Azka and Yadav's (2021) CTIM model to integrate CT effectively into diverse disciplines, will provide this study with a clearly defined scope and purpose. The study will employ qualitative methods to explore and answer the research questions. This research builds on previous work undertaken by the two lead researchers from 2021-2023 with the help of additional research assistants (Fox-Turnbull W. et al., 2024; Fox-Turnbull et al., 2023). The main research question is

> *How can using interdisciplinary integration of computational thinking and writing enhance teachers' knowledge and skills in both disciplines?*

It breaks down to three sub-questions:

> 1.*What strategies assist teachers understanding of and implications for the overlapping nature of computational thinking and writing concepts?*
>
> *2.How does teachers' understanding of these overlapping concepts inform their teaching in both disciplines?*
>
> *3.How does teachers' understanding of these overlapping concepts enhance teachers' perceptions of students' learning in both disciplines?*

Participants will be two teachers teaching Years 3-4 and Years 5-6 students from a small-town primary school in the North Island in New Zealand. The study will consist of three phases. In the preparation phase, workshops with teachers, will explore computational thinking and the overlapping concepts between writing and computational thinking culminating in a co-constructed unit of work. In the implementation phase, teachers will implement their unit plan over a four or five-week period in which students will use a computational thinking app, Kete, to scaffold writing through coding sequencing and navigation games. During this phase, researchers will observe and video the teaching and learning. At the end of each day teachers will reflect on their impressions of student learning and their teaching. In the Evaluation phase, using a Stimulated Recall approach (Sezen-Barrie & Kelly, 2017) teachers will view their video footage and reflect on their teaching actions and students' learning, with the assistance of their reflective journal. The research team will interview the teachers as they view the video footage.

Data analysis will include thematic analysis and involve five steps (Cohen et al., 2018; Neuman, 2011). In Step 1, the collected data are sorted and classified based on the research questions they answer. In Step 2, open coding will be used to locate themes (related to the research questions) and organize the data into categories, aiming to bring themes to the surface from deep inside the data and assign code labels for themes. In Step 3, axial coding will assist the organisation of themes to identify the axis of key themes/ideas. In Step 4, selective coding will identify cases that illustrate themes through scanning all the data and previous codes. In Step 5, interpretation and elaboration on the themes/patterns will be used to answer the research questions.

4. CONCLUSION

While the concepts of computational thinking (CT) may take different forms, they share a common foundation aimed at enhancing students' learning experiences. As Wing (2006) highlighted, CT encompasses a universally applicable skill set that fundamentally transforms how students approach problem-solving. This transformative potential makes CT particularly relevant in writing, where structure, creativity, and critical thinking merge. Therefore, by bridging the gap between computational and traditional literacy skills, CT fosters a dynamic learning environment that equips students with the tools to excel in both academic and real-world contexts. This synthesis of research underscores the importance of further exploring and implementing CT-based pedagogies in writing education to fully harness its interdisciplinary benefits.

This proposed study began in November 2024 with teacher workshops and the initial phase of data collection. However, due to unforeseen circumstances within the school, the research was postponed after two weeks. Early findings indicated that teachers had not previously considered the links between writing and computational thinking, yet they expressed strong enthusiasm for integrating the two. We plan to continue the study this year to further explore its potential to inform and enhance teaching practice by highlighting the connections between writing and computational thinking. This includes illustrating overlapping concepts and shared processes between creative or transactional writing and the design and coding of digital outcomes.

Our goal is for teachers to gain practical insights into teaching computational thinking in a way that integrates naturally into existing classroom routines and local culture environment, without demanding significant additional time. We anticipate that students will also benefit from this approach. For example, a 10-year-old boy in our previous study noted that debugging his app was like editing his writing—"but it's way cooler!" This suggests that boys may be especially engaged by drawing parallels between coding and the writing process. Meanwhile, girls—who are often less engaged in computational thinking—may find it more accessible and meaningful when they recognise that developing code follows a similar process to creative or transactional writing. Ultimately, we expect that this integrated approach will lead to improved learning outcomes for both boys and girls, equipping them with transferable skills and fostering a deeper appreciation for the interconnectedness of disciplinary knowledge.

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Empathise and Define: Design thinking for STEM Education in UK Secondary Schools

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ABSTRACT

Design thinking and STEM education have gained increasing prominence with a natural synergy between the two identified; both championing innovation, driving up the economy and in educational terms supporting a workforce for the future. With research into the connected fields at an early stage, this paper explores these contexts in UK education for the first time. Importantly it steers away from prior research which is fixated on case studies and instead focuses on understanding (and empathising) the perceptions of teachers to define what teachers understand regarding design thinking and STEM education and how these can be used in UK education settings. Research results were gained through a questionnaire across different school settings, followed up by an in-depth interview across STEM subjects, providing rigour and consistency in the research findings. The results offer surprises, confirm prior judgements and provide suggestions to developing strong practice moving forward whilst the case is made that the T in STEM is alive and kicking.

Keywords: *Defining, Design Thinking, Empathising, STEM Education.*

1. INTRODUCTION

Design thinking (DT) is a contemporary concept, even more juvenile than the concept of science, technology, engineering and maths (STEM). However, the academic research in the field has accelerated over the last 15 years (Panke, 2019) with the number of books available on the topic also steadily increased. It is notable that Andreas Schleicher, Director for Education and Skills Organisation at the Economic Cooperation and Development (OECD), identified DT as one of five key areas for knowledge development during a keynote speech a decade ago (Schleicher, 2015), referring to inspiration from the Center for Curriculum Redesign (CCR); at a time when education in England was focused on the so-called knowledge-rich ideology rather than the skills and creativity (e.g. McLain et al., 2019; Gibb, 2017).

Research regarding DT at this stage is relatively immature compared to more established models of design. Many books on DT lend themselves to business or architectural thinking and those with an educational focus tend to relate to US or East Asian education. However, the growing trend in DT has emerged from the branding at Stanford University who use a 5-stage model as

part of this process. Even though DT has existed in many forms in previous years, this 5-stage model has given a clear structure for others to follow. DT is a process that can encourage innovation and drive up the economy (Curedale, 2019); these are benefits that have also been heard in STEM education, suggesting a mutual benefit. The literature search with regard to these shared fields is limited but does suggest mutual benefit between the fields of DTand STEM education, although this research often relates to specific cases studies.

We interrogated the connected fields of DT and STEM education which can be seen in the literature review. Here noticeable gaps in the research are identified. No existing research relates to empathizing with teachers to understand their own perceptions regarding DTand no research exists relating to UK secondary school education. These become two of the key foci for the research process. If DT is to be used effectively within STEM education, we need to understand better what teachers understand by DT and we need to understand how DT can effectively contribute to STEM education. As a result, these are the three key questions that arose during the research process:

- Do UK secondary school teachers understand what DT is?
- Can teachers define DT and give examples of its use?
- Are there specific opportunities and challenges for delivering DT in UK secondary STEM education?

Through answering these questions, educators can understand how well teachers understand this topic, where it is currently being used, where it can be used further and how teachers can be supported further to use this process in their practice. In the discussion of findings and conclusion section, the results of the research provide great clarity for those with responsibility for organising integrated STEM in their schools and those who have responsibility for subject areas. The results identify how DT can support individual subject areas and integrated STEM, including where it is most appropriately used. It also identifies how teachers can be further supported with implementing DT whilst highlighting suggested areas for further research.

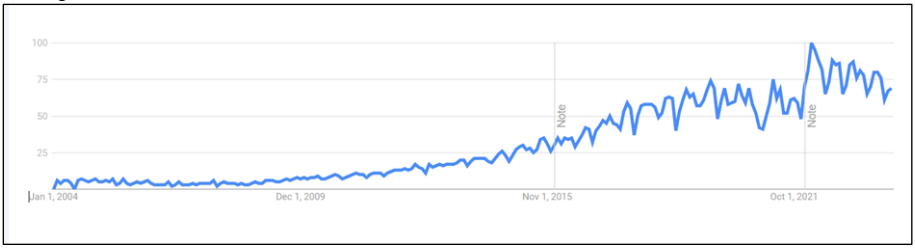
2. BACKGROUND

DT has gained increasing prominence in recent times. Case studies have identified the economic impact of using DT for businesses (Curedale, 2019) whilst exposure in educational fields, particularly Higher Education has also become more prominent, for example Panke (2019) notes that it has transcended business and management education as well as DT schools. A review of existing literature in the field of DT shows that the topic has become more popular as each year has passed over a 10 year period (Panke, 2019) . The content of these books typically focuses on three key themes:

- Business and the economy
- Innovation and product or service development
- Education and research

Further to the world of publications and books, the world of digital reading has also demonstrated an interest in the topic of DT. This is demonstrated by the number of searches on the internet using the search site Google (Curedale, 2019). Below the author hasrepeated this same search to show the latest trend with regard to this research (Google Trends, 2023).

FIGURE 1. *Graph from Google trends that showing the number of internet searches for the term 'design thinking' since 2004*



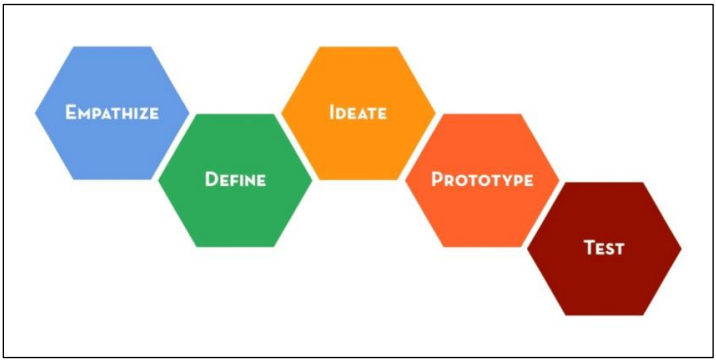
2.1. What is design thinking and why is it becoming so popular?

DT has received a colourful array of definitions. In layman's terms, design and thinking are two separate words in the dictionary. Design can be used as a *verb* – to work the structure or form of something by making a sketch or plan – or as a *noun* – a sketch, plan or preliminary drawing (Collins, 2003). Thinking can be a *noun* – an opinion or judgement – or an adjective – the process of thought (Collins, 2003). For some it is even a *verb*! Britannica dictionary (2023) defines thinking as to form or have (a particular thought) in your mind. This alone shows that the words can be interpreted in different ways. Bringing the words together as a noun, DT could be describing an opinion or process for a sketch or plan. This is supported by Ambrose and Harris (2010) who define DT as a *"noun - the act or practice of using your mind to consider design"* Using the verb definitions, DT is a verb that focuses on using one's mind to make decisions regarding these sketches or plans. This concept of DT is supported by many. Goldman and Zielezinski (2022) write that DT *"is another kind of problem-solving aiming to solve problems which do not have solutions"* whilst Razzouk and Shute (2012) define it as *"an analytic and creative process that give a person, opportunities to experiment, create, prototype models and redesign."*

These definitions focus only on the process and are contradicted by others who take the words beyond their original definitions and see DT as an authentic approach which is focused on understanding people. Hsiao et al (2017) define DT as *"a mode that centres on humans"* whilst Spencer and Juliani (2016) explain that it *"starts with empathy to really understand problems before attempting to create solutions."* It is this user focused approach that makes DT unique and has been recognised for its contributions to support business practices (Panke, 2019). Amongst the confusion of different definitions, it is little wonder that Barsalou (2018) notes that *"DT is more mystical than Tibetan Buddhism"* whilst Li et al (2019) note how the ambiguity of the different meanings has contributed to difficulty in operationalising DT. It is therefore vital to arrive at a clear definition regarding what DT is, if it is to be used further.

Whilst some have seen DT as a process *or* a human-centred approach there are many that view DT as a process *and* a human-centred approach. Brown (2020) defines DT as *"a methodology that imbues the full spectrum of innovation activities with a human-centred design ethos"* For others the DT approach is an interdisciplinary approach with roots in engineering, design and social sciences (Ozturk & Korkut, 2017). Carroll (2015) defines *"design thinking as a human-centred, prototype-driven innovation process that provides a robust scaffold for divergent problem solving."* This is further supported by Lee (2018) who defines DT as *"a human-centred methodology that democratizes the design process by providing the structure and tools for every person to think and behave like a designer."* Forming these differing definitions together into a succinct definition the author concludes that ***"design thinking is a user focused approach to producing innovative solutions to problems"***

FIGURE 2. *The 5-stage design thinking model that is taught at Stanford University (2023)*



DT has always been happening but the DT that we know that has increased in popularity, gained its notoriety through Stanford University who state that DT is a methodology for creative problem solving (2023) whilst also helping us to understand people's needs and empathise (O'Donoghue, 2023). This supports the author's earlier summary definition that DT is a process AND is human focused. To support learners in understanding the process of DT, Stanford University have formed a model featuring five steps (**FIGURE 2**).

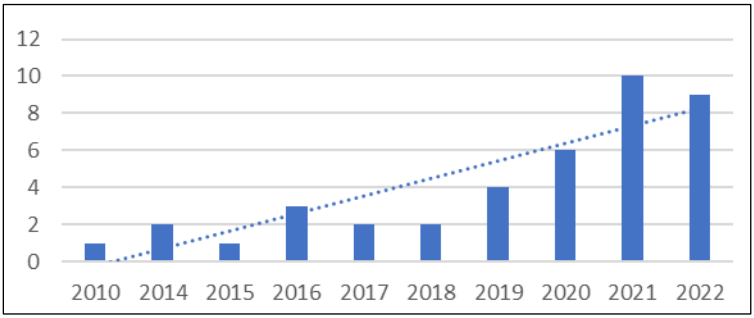
2.2. Design Thinking and STEM

Searching Google Scholar, using the terms "STEM education" and "design thinking" identified a further 44 academic articles relating to both DT and STEM education. Reviewing the year of publication for these articles reinforces the trends previously identified that this is becoming an increasingly stimulating topic.

An overview of these 44 articles identifies a consistent theme that DT in STEM education can provide positive impact for students such as improved engagement, communication amongst peers, empathy, motivation and in some cases, greater understanding in the integrated disciplines. Yet concerns are raised regarding the structure needed for learners and the professional development support for teachers. With the research regarding DT in STEM education at such an immature stage, there is still much to explore. Many of the texts concern United States, Turkish

or East Asian education yet none of the research was focused on education in the United Kingdom. A gap has emerged; a wicked problem indeed! Existing research focuses on specific cases studies or literature reviews. Ironically few enter the 'empathy' phase that is the fulcrum of DT. There is little focus on teachers and defining their needs. It is as though many authors have forgotten the DT model and jumped straight to the ideation or prototype phase. If DT is to flourish, we need to understand better what teachers' perspectives and understanding are of DT if it is to be successfully implemented in STEM education.

FIGURE 3. *Graph showing the number of academic research articles relating to both design thinking and STEM education, that have been produced each year since 2010.*



3. METHODOLOGY

The research questions underpinning this study were:

(i) Do UK secondary school teachers understand what DT is?
(ii) Can teachers define DT and give examples of its use?
(iii) Are there specific opportunities and challenges for delivering DT in UK secondary STEM education?

The research carried out was conducted with practicing teachers in UK secondary schools with consent sought for their participation in the research process. In the first instance, study was open to all teachers as those involved in STEM activities can come from a variety of disciplines and backgrounds (El Nagdi et al, 2018). The study adopted a mixed method approach featuring quantitative and qualitative responses, with quantitative results taking the lead with supporting qualitative responses. Quantitative data was gathered to gain an accurate understanding from a large dataset to identify trends, with the qualitative data providing rich insights.

3.1 Analysis

The results of the survey were recorded anonymously using Qualtrics online research tool. Respondents could only be identified if they chose to record their contact e-mail address, and the data were pseudonymised prior to analysis. Where qualitative responses were recorded, they were

thematically analysed using open coding, which were iteratively refined and grouped. The data were analysed separately from participants in six schools, to compare results and analyse the similarities and differences between datasets. The data were cleaned, removing incomplete responses and ineligible participants from settings other than mainstream secondary schools (i.e. primary school or special school) From the survey results, emerging themes were identified and potential participants to interview were identified. To ensure consistency, all interviews were carried out online with recorded transcripts kept in a password protected drive. Transcripts were thematically analysed to identify emerging themes to triangulate with the questionnaire responses.

4. FINDINGS

The initial pilot stage of Phase 1, surveyed a total of 54 secondary school staff from School A. After screening and cleaning the data, 42 eligible respondents were identified. The results from school A show a limited understanding of DT. Whilst 29% of teachers have heard of DT, 24% believe they understand what it means. Yet only 1 of the 42 teachers could give an accurate definition of the term stating that *"design thinking is an iterative process that focuses on producing new ideas for problems based on user needs."* A further 19% of teachers from school A could give a definition that featured inaccuracies such as *"a process to support problem solving"* or *"designing solutions with your audience in mind."* In these instances, respondents failed to identify both a process and the focus on the user. Confidence from teachers that they use DT was low with 24% expressing confidence that they used DT in their setting, this confidence improved when they were presented with a definition (confidence rose to 50% in respondents) or when presented with the DT model (confidence was at 36% with respondents). Where teachers used DT, it was most commonly used as part of lesson teaching or an activity that students completed (21% of respondents). In lesser cases it is used as part of their own teaching practice (2%), lesson planning (5%), supporting individual students (2%) or in implementing wider school systems (7%). This was a surprise to the researcher as many of the examples showed that teachers see a purpose for DT to be used beyond the classroom and to support their own practice.

Where teachers were asked to give examples of using DT, only 7% of responses were broadly accurate. One such example was *"music students use this approach; who is the gig for? What are the requirements (length of set, location/audience needs)?."* 12% of responses included a clear process but did not mention the user; for example, *"planning an experiment to collect data for a particular hypothesis."* 5% of responses mentioned the user but not a process; for example, *"working with a pupil who struggles with their behaviour choices to come up with solutions together that will benefit them."* When the results were interrogated further only one respondent could confidently say that they have heard of the term design thinking, know what it means, give an accurate definition and an accurate example of use in their own practice. The indications from this first stage of research are that teachers understanding and use of DT is very limited but once probed further, there is some application of it in small sections.

The questions carried out in the survey were repeated with two further phases. In phase two, 60 secondary teachers from across 5 different secondary schools completed the survey. These 5 schools have a total of 289 teachers giving a lower response rate of 24%. Part 3 of the questionnaire phase was widened to allow teachers from beyond the sample schools the

opportunity to complete the survey. This would allow further comparison of results to gain confidence in the process whilst also widening the field to create a large sample for sub-categories such as teachers' subject specialisms or experience in teaching. In the third phase, the survey link was made available and shared through the social media platform X. The message promoting the survey link was shared (reposted) 82 times by users, leading to 26,000 views of the posts. 96 secondary teachers responded during this phase. The results in both phase 2 and phase 3 of the survey produced comparable trends in the results. These are shown in the tables below.

4.3. Quantitative Data

TABLE 1. *Have you heard of the term design thinking?*

Phase	Yes	No
Phase 1 *(n=42)*	29%	71%
Phase 2 *(n=60)*	18%	82%
Phase 3 *(n=98)*	33%	67%
Total *(n=198)*	**28%**	**72%**

TABLE 2. *Do you know what the term design thinking means?*

Phase	Yes	No	No answer
Phase 1	24%	74%	2%
Phase 2	17%	83%	
Phase 3	25%	75%	
Total	**22%**	**77%**	**1%**

TABLE 3. *Please write a definition of design thinking in your own words.*

Phase	Identified user AND process	Identified user OR process	Vague definition	Limited definition	No response
Phase 1	2%	19%	40%	7%	31%
Phase 2	5%	10%	33%	10%	42%
Phase 3	6%	13%	27%	8%	46%
Total	**5%**	**13%**	**32%**	**9%**	**41%**

TABLE 4. *Consider the following definition of design thinking: "Design thinking is a user focused approach to producing innovative solutions to problems"*

Phase	Very confident	Confident	Unconfident	Very unconfident	No response
Phase 1	7%	40%	48%	5%	0%
Phase 2	7%	33%	47%	13%	0%
Phase 3	8%	43%	33%	14%	2%
Total	**8%**	**39%**	**40%**	**12%**	**1%**

TABLE 5. *Design thinking is modelled using five identified stages: 1. Empathise; 2. Define; 3. Ideate; 4. Prototype; 5. Test. With respect to this model, how confident are you that you use 'design thinking' in your education setting?*

Phase	Very confident	Confident	Unconfident	Very unconfident	No response
Phase 1	5%	31%	50%	14%	0%
Phase 2	12%	35%	45%	8%	0%
Phase 3	9%	35%	36%	17%	2%
Total	**9%**	**34%**	**42%**	**14%**	**1%**

TABLE 6. *Please give an example where you feel you have used 'design thinking' effectively within your own education setting. Analysis by implementation.*

Phase	Student Activity	Whole School	Student Support	Lesson Planning	Lesson Delivery	No response	Unclear example
Phase 1	21%	7%	2%	2%	5%	60%	2%

Phase 2	13%	8%	3%	8%	10%	53%	3%
Phase 3	29%	6%	1%	3%	2%	56%	3%
Total	**23%**	**7%**	**2%**	**5%**	**5%**	**56%**	**3%**

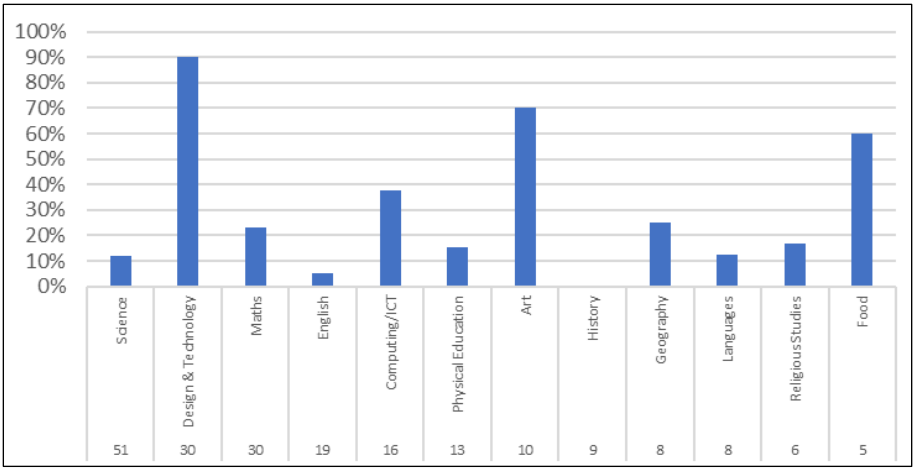
TABLE 7. *Please give an example where you feel you have used 'design thinking' effectively within your own education setting. Analysis by accuracy of example given.*

Phase	Broadly accurate answer	Answer refers to the process but not the user	Answer refers to the user but not the process	Answer has some relevance but is unclear	Unclear answer	No answer
Phase 1	7%	12%	5%	14%	2%	60%
Phase 2	3%	15%	7%	18%	3%	54%
Phase 3	8%	21%	4%	8%	3%	56%
Total	**7%**	**17%**	**5%**	**13%**	**3%**	**56%**

When the results were probed further only 4 respondents of those surveyed could confidently say that they have heard of DT, know what it means and give an accurate definition and an accurate example of use in their own practice. This data set conclusively proves that there is a limited understanding regarding DT amongst secondary school teachers in the United Kingdom.

4.4. Trends in the data

FIGURE 4. *percentage of secondary teachers who have heard of the term design thinking according to the subject that they teach. The number of respondents is indicated with each subject at the base of the column. Only subjects that received 5 or more responses are included.*



Reviewing the subgroups in the data it was apparent that there were very few variations in the responses. However, subject specialisms revealed clearer differences. Design & technology (D&T) teachers scored highest with 90% having heard of DT. Art also had a strong score (7 out of 10), as does food (3 out of 5) which is likely explained as D&T and food are often placed in the same curriculum group in UK secondary schools. Computing also has a reasonably high score with 6 out of 16 teachers having heard of DT. These subjects all received scores higher than the

whole sample (28%). This indicates a higher understanding in creative and technological subjects. Whilst the STEM subjects of D&T and computing scored higher, the STEM subjects of maths and science scored lower with 23% for maths and 12% for science. The difference in subject trends here identifies a line of enquiry for further investigation. Exploring the role of teachers did not reveal significant findings. Similar results were produced for teachers, senior leaders and middle leaders. This was also true of teachers age and teaching experience. The only factor that affects whether teachers have heard of DT, is their subject background. This factor was explored further and the author noted that the only 4 teachers that could accurately define and give an accurate example of DT were D&T teachers. It is conclusive that D&T teachers have a strong grasp of DT.

4.5. Confidence following definition and model

Only 23% of the sample population had heard of the term DT. However, when respondents were told that *"design thinking is a user focused approach to producing innovative solutions to problems."* the confidence increased from 23% to 47% across the whole population. The subjects represented in this diversified with science particularly notable. When presented with this definition, 30% of science teachers felt confident that they used DT (rising from 4% previously). Respondents were presented with the 5 stages DT model from Stanford University. Following this definition, confidence was at 43% which was higher than the original 23% of the sample. These findings give confidence that DT is happening amongst nearly half of UK secondary school teachers. However, teachers initial understanding of DT is weaker. This opens up a line for further investigation. Giving examples of how DT is being used, the most popular answer was a learning activity taking place, in line with the intention of DT. For example, one teacher said their students do *"product designs for a quadruple amputee, with the user being consulted throughout the process"* whilst another stated their students *"use a client brief/scenario for media or non-examined-assessment projects involve a gif for computer science."* Other teachers indicated that DT helps them plan lessons whilst others commented on implementing school systems or giving individual students' support. This variation in response, presents an opportunity to explore this area further to understand how DT could or is being used with learners by secondary school teachers.

5. DISCUSSION

The consistent theme amongst the research is that where opportunities open for discussion, confidence increases. The survey has scratched the surface when exploring UK secondary school teachers understanding and use of DT, but it has not explored this deep enough. This supports the initial methodology to pursue further responses through interview. By presenting clearly what DT is, how it is framed and explaining distinct examples of DT, further discussion could be had with research respondents. As there has been some disparity in the answers of those from different STEM disciplines, the interviews will focus on teachers from the STEM disciplines of computing, D&T, mathematics and science to pursue this line of enquiry. The key areas to pursue further were:

- How DT is used by teachers in their own subject areas in the STEM disciplines and how it could be used further upon a clear understanding of DT?
- Where it is relevant to use DT in subject teaching and where it is not relevant to use DT in subject teaching?
- What is a reasonable proportion of the curriculum at both KS3 and KS4 to cover through DT?
- How DT is and could be used by teachers in STEM activities?
- Where DT can and cannot be used within STEM thinking?
- How DT can positively impact the STEM subjects?
- Which STEM subjects are best suited to DT?
- Which subjects outside of STEM are best suited to DT?
- What the barriers are to teachers using DT?
- How teachers feel they could be better supported to implement DT?
- Any other opportunities to use DT in their work.

6. INTERVIEWS

TABLE 8. *Confidence in design thinking indicated from survey with interview code and subject*

Code of teacher	Subject	Confidence
C1	Computing	High
C2	Computing	Medium
C3	Computing	Low
D1	Design & Technology	High
D2	Design & Technology	Medium
D3	Design & Technology	Low
M1	Mathematics	High
M2	Mathematics	Medium
M3	Mathematics	Low
S1	Science	High
S2	Science	Medium
S3	Science	Low

Twelve interviewees were selected from the initial sample, whereby they gave their consent to be contacted for interview. The interviewees were selected through a cluster sampling method. For each of the UK STEM disciplines (science, maths, D&T, computing), three teachers were selected; one teacher who answered with confidence regarding DT, one teacher who answered demonstrating poor confidence and another teacher who responded with mixed confidence. Each interviewee was presented with a definition of DT, the Stanford University model and examples of DT being applied in different settings so that they understood the process clearly and how it is applied. This was then repeated in the context of STEM. The table below shows the key codes that will be used when the author refers to interview respondents in the results analysis. There were a total of ten key themes that emerged through the interviews which are outlined below.

6.1. There is a notable difference between the STEM subjects regarding how DT can be used

D&T and computing teachers spoke with great confidence. For example, C2 commented that students do a *"component on design interfaces; students have to create a touch screen dashboard based on that problem. There's a human element to it because they have to consider accessibility and the target audience"* Maths and science teachers demonstrated a lack of confidence but when pushed further they could identify opportunities. *S3 became excited when reflecting on a recent lesson stating "I'm just thinking about my lesson today; students were struggling with the concepts of speed and drag. I could have done this as a design thinking task. They could have had a slope and car and measured the results. Oh, that's great! If they did it like that, they would have understood this themselves."*

6.2. There is a balance needed between subject knowledge and DT

Nine interviewees commented on specific knowledge being an aspect you could not teach through DT. For example:

- *"Subject knowledge such as spreadsheets, use of data and the bell curve"* (C2)
- *"There are specific practical tasks that students need to know."* (S2)
- *"Topics like material properties and various types of materials."* (D2)

6.3. Key Stage 3 provides more opportunity to deliver DT than key stage 4

When summarising the potential curriculum content that could be covered through DT, for KS3 and KS4 respectively, science was 48% and 20%, maths was 48% and 30%, computing was 49% and 31% whilst D&T was 83% and 80%. Key stage 4 is limited due to the pressure to cover a rigorous curriculum and for students' exam performance.

6.4. Design & technology is best placed to deliver DT

Ten interviewees stated that D&T is the STEM subject that is most aligned to DT whilst D&T teachers felt that on average 83% of the KS3 curriculum and 80% of the KS4 curriculum could be covered through DT. This was significantly higher than any other subject area.

6.5. Integrated STEM provides better opportunities than individual subject teaching to deliver DT

All teachers interviewed can see how DT can be delivered through integrated STEM. C3 gave the context of games design *"it's not badged as empathy, they're badged as common-sense approach to the way the creator will create."* S2 said *"We've done a new product design through Samsung, where our year nines work on a brief to solve a problem, brainstorm loads of ideas in a short space of time."*

6.6. DT provides a pathway to improve connections between the STEM subjects

The most common benefit identified was the use of shared language and knowledge. C3 supported this saying *"hopefully lots in my class have gone, we did that in physics, we did it in circuits when I teach logic diagrams. There's lots of cross-curricular connections."* S3 also commented that *"maths is now about 1/4 of a science paper."*

6.7. Empathy and the arts are important in the context of DT

Seven interviewees mentioned the arts as most aligned with DT beyond the STEM disciplines. This was a reflection of the creative and emotive aspects of DT. This would support the concept

of STEAM as opposed to STEM, a point supported by Marr (2020) and Xanthoudaki (2017). Five of the interviewees mentioned the social sciences and humanities subjects. With empathy being the first stage of the process in DT, this highlights an area for further research.

6.8. Soft skills can be developed through DT which are of great benefit to the learner

Nine interviewees mentioned soft skills that are not explicitly clear in the curricula taught. Examples include problem solving, decision making, resilience and project management.

6.9. Effective support needed to deliver DT

Seven interviewees noted the need to understand the impact of DT whilst six mentioned concerns about capital issues such as time and resource investment - an implication for decision-making and investment from senior leaders.

6.10. Strongest teachers use tools and strategies

The strongest teachers referenced specific strategies that they used. M1 said "*the acronym I see used most often in maths problem solving is called RUCKSAC so it's R for read etc"* D1 explained *"some of the classic tools like SCAMPER and ACCESS FM, which are defined as being design thinking tools as ways of analysing."*

7. CONCLUSION

The research has consistently shown that teachers have a limited confidence and understanding of DT. However, this does improve when presented with a definition or the model from Stanford university. D&T teachers in particular have a very strong understanding of DT whilst there was an element of strength from computing teachers. This gives an increasing prominence to the 'T' in STEM – both D&T and computing. Teachers felt that integrated STEM education provides the best opportunities to deliver DT. This supports the earlier notion that DT and STEM education have a natural synergy. *If* DT is to be used within curriculum time, there is greater scope at KS3 level which has greater freedom compared to the exam pressured time at KS4. This restriction on curriculum time was previously highlighted by Blackley and Howell (2015) and should be considered by curriculum leaders. DT supports 'softer skills' that aren't in the curriculum but are demanded by those in industry such as problem solving, resilience and managing deadlines. This again supports the synergy of DT and STEM education.

Teachers in each field felt that DT was not appropriate where subject specific knowledge and/or skills needed to be taught. This backs the previous points made by Lee (2018) and Spencer & Juliani (2016) with regard to the conflict between skills and knowledge. Further research is needed into the relationship between these two realms. If DT is making use of subject knowledge, then the DT model needs reconsidering with regard to a 6th underlying principle of 'knowledge' and where this fits within the model. Interviewees mentioned the importance of the arts to DT. This lends itself to the concept of 'STEAM' (where A represents art) rather than 'STEM.' This concept is already supported by the likes of Marr (2020) and Xanthoudaki (2017). Continued reference was made to social sciences and humanities due to 'empathize' being the first key phase in the DT model. STEM teachers need to look beyond their own disciplines and look sideways (Banks & Barlex, 2021) to understand more about other subjects

and implement good practice. At a time when education often emphasises the 'S' and 'M' from STEM, the reality is that the 'T' and 'E' are important for industry. DT in integrated STEM education can provide an excellent opportunity to bridge this divide. The research highlights the benefits DT can bring to STEM education and makes a strong argument for the importance of D&T and computing. This research took the DT approach literally, empathizing with UK secondary teachers to define the situation presently. With the empathy and define stage completed with regard to DT in STEM education, the next phase for researchers is the idea and prototype phase. Based on the research findings, teachers wish to see the strategies that can be used in the classroom and the impact of these. An exciting phase to continue the research in this respect.

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To Choose Technology or Not – investigating students' perceptions and attitudes toward future work and higher studies

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Abstract

In Sweden, all students study technology during compulsory school. In upper secondary school, they choose a program based on their own interests and future plans. This pilot study utilizes the PATT-SQ-SE questionnaire to explore its applicability in a different context. The aim is to investigate upper secondary school students' attitudes and perceptions of technology and technology education, based on their experiences during compulsory schooling. In the study, students in a Swedish midtown, ages 16-19, were surveyed. They have completed their technology education in compulsory school but have chosen to pursue other programs in upper secondary school, such as Social Sciences, Natural Sciences, or Child and Recreation.

The survey was analysed through the attitudinal components; affective, behavioural, cognitive, and the relationship between them.

The findings provide insights about what these students retain from their technology education in terms of attitudes and teaching content. By examining their views and experiences, this study seeks to provide insights and the impact of technology education in compulsory school.

Key Words: Attitudes, Compulsory school, Perception of Technology

1. INTRODUCTION

By the time Swedish students reach the age of 16 and complete compulsory schooling, they will have received basic training in technology education. Unless they specialise in technology at secondary or higher education level, they will not study technology as a subject, but they will have acquired a foundation in technological literacy. Based on that, the authors of this paper have become interested and curious to investigate attitudes and perceptions among youths that have completed their basic training in technology education and have chosen NOT to study the subject of technology at secondary school.

The attitudes towards technology among young people is a rather well examined area. The pupils' attitudes toward technology (PATT) survey, developed by Raat and de Vries (1986) in the 1980s. It was intended to explore students' (ages 13-15) attitudes toward and perceptions of technology when entering technology education (Kőycű & De Vries, 2016). However, the reverse situation, attitudes toward and perceptions of technology when exiting technology education have not yet been researched in more depth.

In Sweden, the subject of technology is mandatory for all students during compulsory school (age 7-16). The subject of technology is multidisciplinary, including for example technology related to humans, society and the environment, technical solutions and working methods (c.f. Nordlöf et al., 2022), with an overall aim of providing a foundation for technological literacy (Skolverket, 2022). In upper secondary school (age 17-19), they choose a program based on their own interests and future plans. There are 18 in total, of which 12 are programs that are vocationally oriented and 6 are programs that prepare the students for higher studies. One of these is the Technology program, which prepares students for studies e.g. engineering and web development. This is the only program where students study the subject of technology in upper secondary school, but in the other programs there are technical elements in the training to varying extent.

1.1. Aim and Research Questions

This pilot study utilizes the PATT-SQ-SE questionnaire (Svenningsson, 2024) to explore its applicability in a different context. The aim is to investigate upper secondary school students' attitudes and perceptions of technology education, based on their experiences conducted during compulsory schooling. The pilot study takes is based on the following research questions:

> *What are upper secondary school students' attitudes towards and perception about technology and technology education?*
>
> *How can the PATT-SQ-SE be used to study students' attitudes towards technology in upper secondary schools?*

2. LITERATURE REVIEW

The PATT survey has been used in several countries and modified for different contexts. In the 1990s the PATT questionnaire was shortened and modified for an American context, PATT-USA (Ankiewicz, 2019a). The PATT-USA survey has also developed into questionnaires suitable for younger children PATT-ELEM (for elementary school) by Holter (2016) and PATT-G4, focusing on fourth graders in the USA (Papadopoulos, 2021). In Belgium, the survey was further shortened (Ardies, et al., 2013). This shortened questionnaire (PATT-SQ) contains 24 attitudinal items, for ages 12-15.

These traditional PATT-questionnaires consist of a main section that aims to investigate the affective component of attitudes (Tzeng & Yu, 2023; Ankiewicz 2019a; Ardies et al., 2013). The PATT-NL and PATT-USA also have an essay part, where respondents are asked to describe what they think technology is in writing, The essay-part and the concept scale were not included in the PATT-SQ questionnaire. For a Swedish context (ages 12-15) the PATT-SQ questionnaire was developed to survey and explore relations among the affective, behaviour (intent) and cognitive components of attitudes (Svenningsson, 2024), called PATT-SQ-SE. The affective component was surveyed through the items in PATT-SQ related to student interest in and boredom with technology. The behavioural component was surveyed through responding students' career ambitions in the technological field, which was interpreted as behavioural intent (see Fishbein & Ajzen, 2010). The cognitive component was surveyed using an essay part and quantified by using Mitcham's (1994) manifestation of technology (Svenningsson, 2020), named the Mitcham Score. The Mitcham Score is a quantification of a student's broadness of their technological perception. Results from the PATT-SQ-SE showed relationships between the three components, where the affective component had a positive relationship to both the cognitive component (the Mitcham Score) and behaviour (behavioural intent) (Svenningsson et al., 2022). The relationship between the cognitive and behavioural component though, differed between girls respectively boys. For girls there was a relationship between cognitive and behaviour, meaning that girls with a broad perception of technology were more likely to be positive about a technological career. Among boys in that study, there were no statistical relation, results illustrated in fig.1.

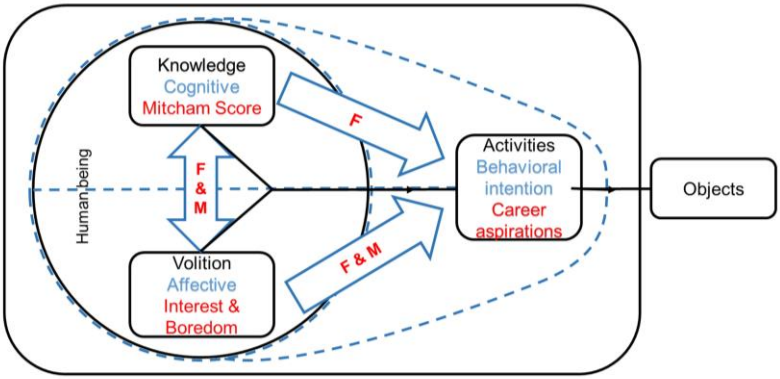

Fig 1.
The above model is adapted from Ankiewicz (2019a) and used by Svenningsson et. al (2022) to illustrate the relationship between the attitudinal components.

2.1. Theoretical Framework

An attitude is often represented in dimensions such as good versus bad, or likable versus dislikeable toward an object (Ajzen 2001; Eagly & Chaiken, 1993). Traditionally attitudes have three components: affective, cognitive, and behavioural (Ankiewicz, 2019b; Eagly & Chaiken, 1993). The affective component involves how a person feels toward an object. The cognitive aspect has to do with a person's conception, belief, prior experience, or knowledge about an object. The behavioural aspect involves a person's actions in relation to an object (Aiken, 2002). This traditional approach has been used in research on pupil's attitudes toward technology (e.g. Svenningsson, 2024). Moreover, in technology education the theory of attitudes has been combined with Mitcham's (1994) framework for technological knowledge, based on *knowledge*, v*olition*, *activities* and *objects* as four modes of technology. Mitcham (1994 p.169) presents this as a model. This model was adapted in an attitudinal context by Ankiewicz (2019a) and tested by Svenningsson et. al (2022), where the relations between the attitudinal components were researched (see fig.1). This model is used (and tested) as a theoretical foundation in this pilot study (but in another context).

3. METHODS

This is a pilot study to test the PATT-SQ-SE questionnaire. The questionnaire consists of statements that students respond to on a five-point Likert scale and open-ended questions to gather information of students' perception of technology.

3.1. Data Collection and Participants

Data was collected during the spring of 2025, via an adapted version of PATT-SQ-SE survey, and was distributed to the headmaster of an upper secondary school in a mid-sized town in Sweden. The school offers the Natural science program, the Social Science program and the Child and Recreation program. In addition, the students can choose a mixture of Natural Science and the Social Science programmes The Natural Science program provides a broad foundation for higher studies such as engineering as well as for scientific studies and medical training. The Social science program prepares students for higher studies for example within law, social work or education. The Child and Recreation program prepare for work in e.g. pre-school or higher studies in education, health or social work. The survey was distributed to all students through the digital platform that the school uses to communicate with the students. It was voluntary to participate and in total 35 students (26 girls, 9 boys) completed the survey. The participating students are between 16 and 19 years old.

The survey was shortened to focus on items that were clearly surveying the affective component of attitudes (10 items regarding; perceived boredom 4 items and interest 6 items). While the behavioural component was considered as the intention to pursue a career in technology (4 items) (see Svenningsson et. al (2022., p1549) for a complete list of attitude statements). The cognitive component is surveyed through two open ended questions. The Mitcham Score method was used (by Svenningsson, 2020), to quantify the students' written responses to the two open ended questions:

> *Describe what you consider to be technology (not the school subject technology)* and
> *If you were to describe the school subject technology for anyone who has not studied it in school themselves, how would you describe it?*

With this method, every student receives a score 0-4 points on how broad their response to the two questions is, based on how many aspects of Mitcham's (1994) manifestations of technology are present. In addition, a third question was asked at the end of the survey:

> *What is your best memory from a technology lesson in compulsory school?*

This question will be incorporated into the qualitative thematical analysis of students' perceptions of technology described in section 3.3.

3.2. Statistical Analysis

Initially, the reliability of the constructs used (affective -interest & boredom- and behavioural intention -career aspiration-) was controlled. Mean scores were calculated for the attitude components (including the Mitcham Score as cognitive component) and were separated for boys and girls as recommended by Svenningsson et. al (2022). The Cronbach's alpha indicate that the attitudinal components surveyed (Behavioural α .90 and Affective α .79) are reliable to use as a scale (see table 1).

Table 1.
Reliability of category scales, number of items and scale means (for behavioural, affective & cognitive components) for all respondents and separated based on gender

Attitude component	Cronbach's α	N items	Scale mean	Std. Deviation	Girl/Boy mean
Behavioural intent Career aspirations	.90	4	2.55	1.06	2.27 / 3.36
Affective Interest & Boredom	.79	10	3.28	.71	3.16 / 3.64
Cognitive The Mitcham Score	-	-	2.69	.68	2.73 / 2.56

To get an idea of how students perceive technology, the different aspects of technology are presented with the students' Mitcham Score in table 2.

Table 2.
Distribution of the different aspects of Mitcham's typology in the students' Mitcham Score

Mitcham score	Object	Activities	Knowledge	Volition	N students in each score	Percent of students in each score
0	-	-	-	-	0	0
1	1	0	0	0	1	2.85
2	11	8	4	1	12	34.25
3	18	18	19	2	19	54.3
4	3	3	3	3	3	8.6
Total	33	29	26	6	35	100

Furthermore, statistical analyses were conducted to examine relationships in the data by conducting correlation analyses. Since the Mitcham Score was considered as relatively high, we decided to conduct a thematical analysis of students' perception of technology as well.

3.3. Thematical Analysis

The qualitative thematic analysis, follow the approach outlined by Braun and Clarke (2006), to explore how upper secondary school students perceive and reflect on technology based on their past experiences of technology education in compulsory school. The data consisted of students' responses to the three open-ended questions in the survey (see section 3.1).

Thematic analysis was chosen for its theoretical flexibility and its capacity to provide a rich, detailed account of patterns of meaning across qualitative data. This method allows researchers to identify and interpret themes without being bound to a specific epistemological stance. The analysis followed Braun and Clarke's (2006) six-phase process.

Themes were identified based on their relevance to the participants' understanding of technology, their perceptions of the school subject, and their personal experiences. This approach enabled a nuanced interpretation of how technology is conceptualised and remembered within the context of compulsory education. Our analysis of the survey responses reveals how upper secondary school students reflect on their past experiences of technology education in compulsory school.

4. RESULTS

The results of this pilot study consist of a quantitative result from the PATT-SQ-SE questionnaire. It also consists of a thematical analysis. The two main results are presented as separately in the results section and then collectively elaborated in the discussion section.

4.1. Quantitative Results

The sample in this pilot study is relatively small, therefore focus is to validate the survey and explore relations. To explore the relationships between the three attitudinal components surveyed, a correlation analysis was conducted for the participating students. Boys and girls were analysed as separate, based on recommendation by Svenningsson et. al. (2022). The results indicate one correlation: between Girls' affection and behavioural intention, table 3.

To further understand the lack of relations, the mean scores were separated based on the student's chosen program. The highest mean score in the cognitive component was among the students within the Social science program (2.91). The highest mean score within the affective component (3.62) and behavioural component (3.32) was among the students within the mixed program (see table 4). The mean scores in table 1 are lower in general for the affective component if compared to the Swedish PATT-SQ-SE (cf. Svenningsson et. al., 2022). The behaviour component mean is similar to the Swedish results. Although, the cognitive component has a higher mean among the students in this study, compared with the younger students surveyed in PATT-SQ-SE by Svenningsson et. al., (2022).

Table 3.
Correlation analysis of relationships between the attitude components for girls respectively boys.

		Girls			Boys		
		Cognitive	Affective	Behaviour	Cognitive	Affective	Behaviour
Cognitive	Pearson Correlation	1	0,032	0,183	1	-0,319	-0,498
	Sig. (2-tailed)		0,876	0,371		0,402	0,172
	N	26	26	26	9	9	9
Affective	Pearson Correlation	0,032	1	**,771****	-0,319	1	0,115
	Sig. (2-tailed)	0,876		<,001	0,402		0,769
	N	26	26	26	9	9	9
Behaviour	Pearson Correlation	0,183	,771**	1	-0,498	0,115	1
	Sig. (2-tailed)	0,371	<,001		0,172	0,769	
	N	26	26	26	9	9	9

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.
Mean score descriptives in the based on chosen program, highest mean scores in bold.

		N	Minimum	Maximum	Mean
Social science program	Cognitive	11	2	4	**2,91**
	Affective	11	1,56	4,11	2,97
	Behavioural intent	11	1	3,25	1,82
	Valid N	11			
Natural science program	Cognitive	16	1	4	2,69
	Affective	16	2,11	4,56	3,35
	Behavioural intent	16	1	4,5	2,72
	Valid N	16			
Child and Recreation program	Cognitive	1	2	2	2
	Affective	1	3,33	3,33	3,33
	Behavioural intent	1	2,5	2,5	2,5
	Valid N	1			
Mix of natural and social sciences	Cognitive	7	2	3	2,43
	Affective	7	2,67	4,22	**3,62**
	Behavioural intent	7	2	4,25	**3,32**
	Valid N	7			

4.2. Qualitative Results

Through the thematic analysis, several recurring patterns of meaning emerged from the data. These patterns were organised into seven main themes, each capturing an aspect of how students perceive and remember school technology. Each main theme is further divided into sub-themes, which provide a more nuanced understanding of the students' perspectives. The themes and sub-themes are presented in a summary table to illustrate the structure and depth of the analysis.

Table 5.
Upper Secondary Students' Perceptions of Technology and the Technology Subject. The main themes and sub-themes derived through the thematic analysis.

Main Theme	Subthemes	Examples from Responses
1. Technology as Digital and Electronic	- Computers and Programming - Digital Tools and Systems - Electronics and Electricity	"Programming, working on computers" "Knowledge of digital networks and programs" "Connecting wires and lamps"
2. Technology as Construction and Design	- Building and Creating - Engineering and Infrastructure - Materials and Models	"Building bridges with popsicle sticks" "Sketching and constructing houses" "Understanding how machines work"
3. Technology as Knowledge and Problem-Solving	- Scientific Understanding - Systems Thinking - Real-World Applications	"Understanding how things are built" "Solving problems using tools and methods" "How society is structured"
4. Technology as Creativity and Innovation	- Designing Solutions - Inventing and Experimenting - Future-Oriented Thinking	"Designing future homes" "Creating a mousetrap that worked" "Thinking outside the box"
5. Technology as Every day and Societal Relevance	- Ubiquity in Daily Life - Use Across Professions - Social and Environmental Impact	"All professions use some form of technology" "Learning about Agbogbloshie" "Technology is everywhere"
6. Technology as a School Subject	- Practical and Theoretical Balance - Memorable Projects - Mixed Experiences	"We built cars and bridges" "We programmed games in Scratch" "It felt like a mix of woodwork and art"

7. Uncertainty or Vague Understanding	- Lack of Clarity - Broad or Undefined Views - Memory Gaps	"Seriously no idea, maybe math?" "Everything, really" "Don't remember much"

5. DISCUSSION

With our research questions as a point of departure, this section highlights the most significant findings from the study.

5.1. How upper secondary school students perceive technology and technology education

Mitcham's (1994) manifestation of technological *objects, activities, knowledge and volition* does reappear in our thematical analysis. However, these upper secondary students do in general describe technology in a broader sense than compulsory school students (Svenningsson et al., 2022). Therefore, it was interesting to further examine students' perceptions of technology through analysing their responses to the question about a memorable moment in technology education.

Upper secondary students' perceptions of technology and their experiences with the subject in compulsory school reveal a rich and varied understanding shaped by both practical engagement and conceptual reflection. A dominant theme is **technology as digital and electronic**, where students frequently associate the concept with computers, programming, digital systems, and electronics. This reflects a contemporary view of technology as deeply embedded in the digital world. This theme is an example of technology as an object (Svenningsson, 2020).

Equally prominent is the view of **technology as construction and design**, where students recall building bridges, designing houses, and working with materials like wood, cardboard, or spaghetti, thus are examples of technology as activities (Svenningsson, 2020). The hands-on projects left strong impressions and are often remembered as highlights of their school experience.

Students also describe **technology as knowledge and problem-solving**, emphasising its role in understanding how things work, applying scientific principles, and solving real-world challenges. This theme bridges both theoretical and practical dimensions of the subject and are examples of technological knowledge (Svenningsson, 2020).

Another key perspective is **technology as creativity and innovation**, where students valued opportunities to invent, design, and think about the future. Projects like designing future homes or building functional devices encouraged imaginative thinking and personal expression. This theme can be interpreted as students' technological volition (Svenningsson, 2020).

The theme of **everyday and societal relevance** highlights how students see technology as omnipresent and essential in modern life. They recognize its role across professions and its impact on society and the environment, referencing sustainability and global issues. This theme can also be interpreted as students' technological volition (Svenningsson, 2020).

When reflecting on **technology as a school subject**, students describe a mix of practical activities and theoretical learning. Memorable moments often involve building, programming, or experimenting, though some also mention confusion or a lack of coherence in the curriculum.

Finally, several responses reflect **uncertainty or vague understanding**, where students either struggled to define technology or had limited memories of their experiences. This suggests that while many found the subject engaging, others may have lacked a clear framework for understanding its purpose or content.

Overall, the upper secondary students write broader description of technology than younger students (Svenningsson, 2024). This is evident from the relatively high Mitcham scores among the upper secondary students (see Table 2), as well as limited variation in their scores. One explanation might be that the students taking part in this study are used to formulate and describe complex things as technology. As seen in table 4, students at the Social science program have the highest mean score in the cognitive component (2.91). Their interest in social science subjects means they may have written the richest and most well-developed descriptions, covering multiple perspectives of what technology is.

5.2. How the PATT-SQ-SE can be used to study students' attitudes towards technology in upper secondary schools

The affective and behavioural components of PATT-SQ-SE are reliable to use in Upper secondary school. The mean scores are similar to previous studies in compulsory schools. The only observed relationship between the attitudinal components was between affection and behaviour, for girls. The Mitcham Score had a high mean generally among the surveyed students and no relations between this cognitive component and the other attitudinal components could be observed.

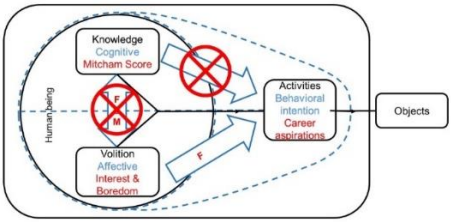

Fig 2.
The above illustration shows students' relationship between the attitudinal components in this study, (cf fig.1).

6. CONCLUSIONS

The aim of this pilot study was to investigate upper secondary school students' attitudes and perceptions of technology education, based on their experiences during compulsory schooling. The findings reveal that students retain a multifaceted understanding of technology shaped by both practical engagement and conceptual reflection. Their responses suggest that compulsory technology education leaves a lasting impression, even among those who do not pursue technology-related programs in upper secondary school.

The study confirms that the PATT-SQ-SE questionnaire is a reliable tool for assessing affective and behavioural components of students' attitudes in this age group. However, the cognitive component, measured through the Mitcham Score, showed limited correlation with the other components, indicating that older students may conceptualize technology in broader and more nuanced ways than younger students. This suggests a need to adapt cognitive assessment tools to better capture the depth of understanding among upper secondary students.

The thematic analysis further highlights that students perceive technology as encompassing digital tools, construction and design, problem-solving, creativity, societal relevance, and personal experiences from school. These insights underscore the importance of diverse and engaging content in technology education to foster lasting interest and understanding.

Overall, this pilot study demonstrates that students' past experiences in compulsory technology education continue to shape their attitudes and perceptions, even when they choose non-technological pathways. These findings provide valuable input for curriculum development and future research on technological literacy and career orientation.

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Comparing the cognitive reasoning processes in team-based engineering design between humans and GPT

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As AI technology based on Generative Pre-trained Transformer (GPT) advances, an inferential model has emerged with GPT-4 that generates results by making inferences about prompts in a manner similar to human thinking. The inference model is designed to produce more accurate outcomes by making reasoning once from the user's input and then re-entering the result values. In this study, we compared the cognitive processes involved in team-based problem-solving within the engineering design process to the inferential results that individuals generate when using a GPT inference model. Halfin's codes were utilized to analyze the cognitive processes optimized for examining the engineering design process, and the findings will be assessed using ratio and sequential analysis methods. Through this study, we aim to determine the comparative strengths and weaknesses of AI thinking versus human thinking in addressing engineering design challenges and to discuss the proper use of AI in design and technology education.

Keywords: Engineering Design; GPT; AI; Cognitive Process

Introduction

Over the past decade, the rapid advancement of Artificial Intelligence (AI) technology has significantly expanded its influence across society, technology, the economy, and education (Holmes & Tuomi, 2022; Yuwono et al., 2024; Zhang & Aslan, 2021). The traditional AI models, often referred to machine learning (ML), focused on analysis such as classification and prediction and performed passive functions (Janiesch, Zschech, & Heinrich, 2021). However, Generative AI (Gen AI) has the ability to perform analyses based on previously trained logics and data to create new results (Baum, 2024). Lim et al. (2023) defined Gen AI as a technology that uses deep learning models to imitate human-like thinking in response to complex and diverse prompts. This creative characteristic of Gen AI has the potential to not only change all industry fields but also enhance human creativity (Pandy, Pugazhenthi, & Murugan, 2025). Especially, the pre-trained models like ChatGPT (Chat Generative Pre-Trained Transformer) are designed to mimic human reasoning within specific contexts, enabling them to define problems and generate solutions in innovative ways. As generative AI continues to evolve, active positive and negative debates are emerging regarding its use, particularly in education, where discussions on appropriate applications are ongoing (Baidoo-Anu & Ansah, 2023; Mittal, Sai, & Chamola, 2024).

In design and technology education, engineering design plays a pivotal role both for the instructional approach and the core content. One of the unique characteristics of design and technology education among school subjects is that it aims to cultivate knowledge alongside skills and attitude such as problem-solving, creativity, teamwork, communication, optimism, critical thinking, and resilience. Wicklein (2006) noted that engineering design provides a solid framework for designing a technology education curriculum. He added that it also serves as a platform for integrating mathematics, science, and technology. Lewis (2004) claimed that engineering design is the key element to integrate engineering concepts into technology education, which helps students learn technological concepts and processes.

When generative AI was first introduced, some schools and regions banned its use in education and even blocked access (Borenstein & Howard, 2021). However, recent discussions on AI in education have extended to the proper use of AI with appropriate guidance. Li et al. (2024) argued that Gen AI can enhance human designers' abilities by analyzing extensive data from various sources and presenting it in an understandable way. They claimed that artificial intelligence can help designers better understand the target features of design problems and produce innovative solutions with the visualization and creativity of AI models. Vartiainen and colleagues (2025) found that using gen AI in design activities can enhance both the creation of design objects and the design process itself. They discovered that gen AI can play as an agency in the decision-making loop of the design process, which helped them identify better solutions. As the influence of generative AI rapidly grows, design and technology education also need to understand how generative AI can improve the design process and creative problem-solving. However, little is known about how the use of generative AI in the design process influences the design activities and outcomes. As a pilot, this study aims to observe and analyze how preservice design and technology teachers use generative AI in engineering design through a think-aloud protocol. Through this research, we will examine how generative AI affects students' cognitive processes during the design process and discuss the effective integration of generative AI in design and technology education.

Research Questions

How do the design processes of preservice teachers using generative AI in engineering design differ from those of students who do not use it?
How do the design outcomes of preservice teachers using generative AI differ from those of students who do not?

Literature Review

1. *Structures of Generative AI and the human brain*

Generative AI (Gen AI) is a kind of artificial intelligence that enhances its performance using neural networks and deep learning algorithms (Baum, 2024). The traditional AI models are based on machine learning (ML) technology, which is primarily designed to analyze data for classification and prediction (Ongsulee, 2017). However, Gen AI is equipped with some advanced features of AI, and one of the core components is deep learning. Deep learning is a specialized training method of machine learning that uses artificial neural networks with multiple layers to analyze existing data (Janiesch, Zschech, & Heinrich, 2021). To build a Gen AI model, data engineers feed large volumes of data to the AI system using deep learning and train the data using neural network models. Neural networks have a similar structure and function to the human brain (Baum, 2024). Like the neurons in the human brain, a neural network of AI consists of many interconnected nodes to process information. The deep learning technology can process all types of data, including text, images, and sounds, which has led to significant breakthroughs in computer vision, speech recognition, and natural language processing.

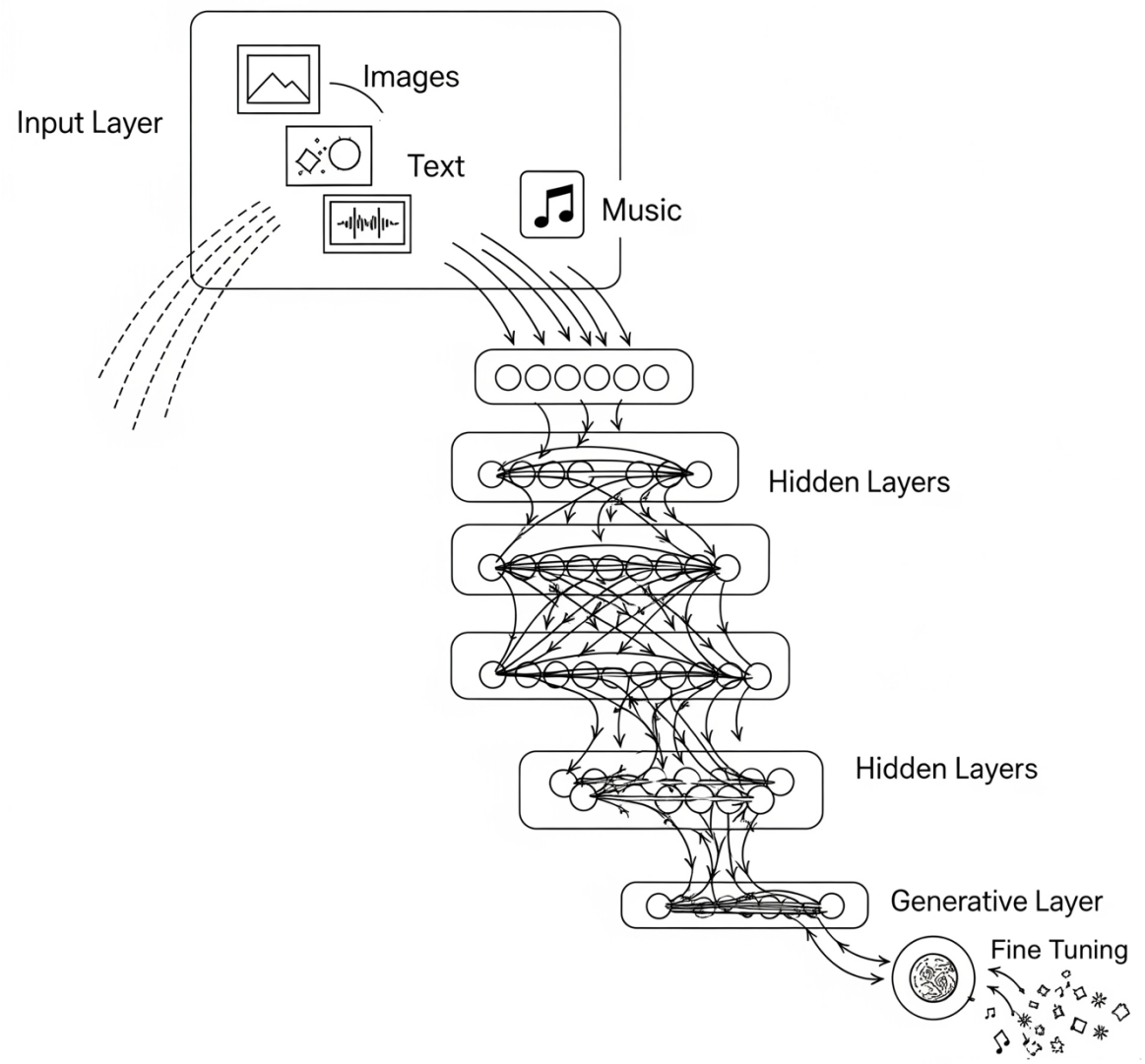

Figure 1 Conceptual model of deep learning of generative AI. Note. Drawn using Gemini 2.5. Prompt: Draw a graphical illustration of the conceptual model of deep learning of generative AI.

2. *Large Language Models (LLMs)*

Large language models (LLMs) are a type of AI system that is designed to understand, interpret, and generate intelligent and creative responses (Baum, 2024). The typical size of fully trained LLMs is a million gigabytes, which is to be fed a large volume of datasets using deep learning. When training a system of LLMs, data engineers use a variety of data sources such as books, articles, websites, and other text-based materials. Chat GPT (Generative Pre-trained Transformer) is a representative system that applies the LLMs to the language model, called natural language processing (NLP) (Nagarhalli, Vaze, & Rana, 2021). Well-trained LLMs have the ability to generate human-like text, answer questions, and complete other language-related tasks like a human.

Recent LLMs have significantly enhanced their capabilities through the use of transformer architectures and the attention mechanism of deep learning. When training generative AI, the transformer architecture allowed LLMs to process numerous inputs efficiently by mapping them

to parallel computing (Baum, 2024). LLMs also employ an attention mechanism that identifies relationships between input data. For example, when the word "design" is input with “education”, the model associates it with the word "technology," improving predictive accuracy for the next word through the attention mechanism. The attention mechanism helps LLMs train on a vast amount of data without human intervention, providing the answer with the input data. Language-based LLMs like Chat GPT use this principle to repeatedly input questions entered by the user into a language model, and the model then presents the next associated word with a probability and selects the one with the highest probability (Ghojogh & Ghodsi, 2020).

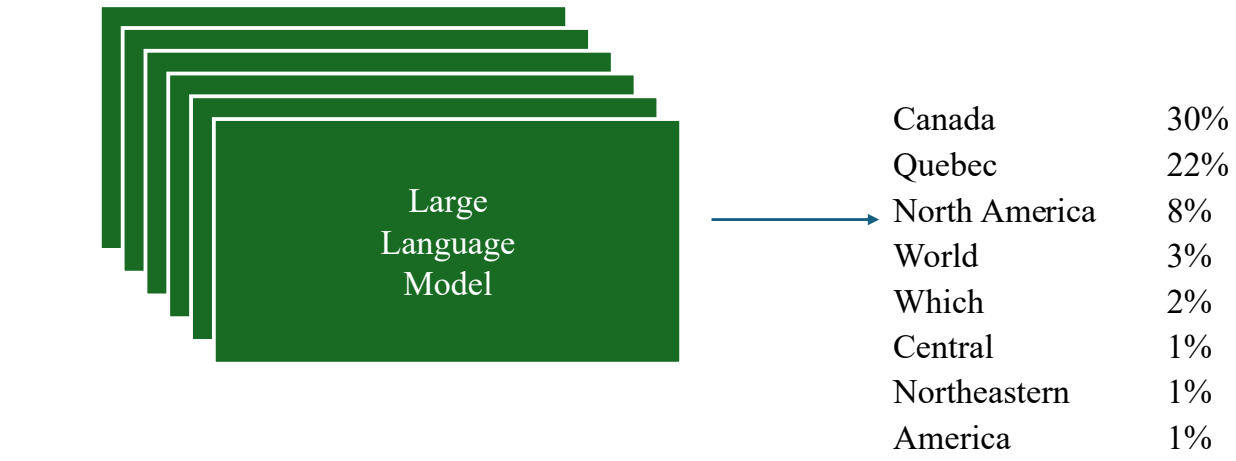

Figure 2 LLMs association mechanism of transformer architectures

In LLMs, those trained for general purposes are called foundation models. Foundational models are generally versatile, but they can also be trained to excel in specific domains or tasks depending on their purpose (Baum, 2024). This targeted training is called fine-tuning, which allows the creation of LLMs optimized for areas such as law, medicine, security, art, and defense. In the case of ChatGPT, the models provided to general users are foundation models, and an example of fine-tuning is when we start a conversation and adjust the output result through a prompt.

3. *Cognitive Models of Creative Conceptual Design*

Research has identified that the engineering design process represents humans' cognitive processes (AUTHORS; Cross, 2001; Strimel et al, 2018); Benami and Jin (2002) proposed a cognitive creative model of conceptual design, presenting that design activities can be expressed as design entities, cognitive processes, and design operations. Design entity is a representation produced from a design activity, and it can have various forms, including function, form, and behavior. Cognitive processes are human mental processes, and conceptual design separates them into two kinds: exploratory and generative processes. The explorative processes include attribute finding, conceptual interpretation, functional inference, contextual shifting, hypothesis testing, and searching for limitations. The generative processes are memory retrieval, association, synthesis, mental transformation, analogical transfer, and categorical reduction. Design operation is a process that materializes design ideas through reasoning activities.

Goldschmidt (1991) noted that designing is a flow of moves from an abstract idea to an artifact of the physical environment, and design operation is an act of reasoning to put forward a coherent proposition to an entity being processed. Design operations have various forms with two folds: internal and external. Internal operations are human mental processes that include suggestions, computing, questions, declarations, apologies, and explanations. The external operations are an actual representation process that includes talking, writing, sketching, pointing, and simulating (Benami & Jin, 2002).

According to the creative conceptual model, designers can generate ideas through a cognitive process, which then produces a mental representation through design operations, which becomes a stimulus for the designer's cognitive process. For example, when designing a new car model, the designer's knowledge, experience, and imagination inspire a design idea, which is then turned into a design representation through a sketching activity, which is then input through the designer's visual senses, resulting in a following cognitive activity, and this process is repeated. In a group setting in a design session, the cognitive processes can be extended to another layer of the peers' mental processes through external design operations such as talking, writing, sketching, or questioning.

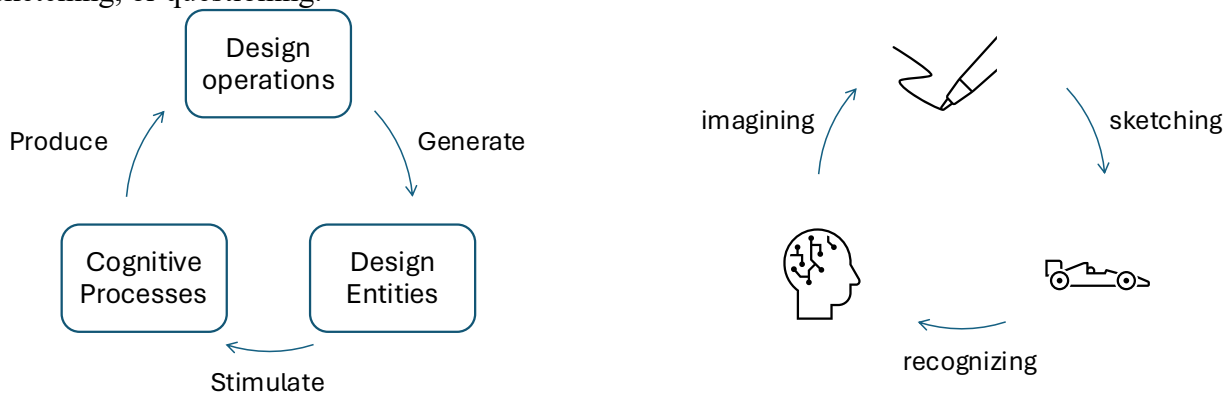

Figure 3 Cognitive Model of Creative Conceptual Design (left) and its example (right)

Research Methodology

Context of the Study

The pilot study will be conducted at a technology teacher education program. The program is housed in a 4-year college that is part of a large urban university system. The demographics of the college are 35% Hispanic, 26% Black, 22% Asian, 11% White, 6% Other, and the median age is 20. The majority of the program students become certificate technology teachers after graduation. This study will examine participants' design behaviors and thought processes while completing a design task in a college course titled Design and Drafting I. Design and Drafting I is a foundational course offered to first- or second-year students in the technology teacher education program. The course lasts 15 weeks and covers basic design techniques, including orthographic projection, sectional views, pictorial drawing, working drawing, and design thinking.

Research Design

This study will have two groups. The design teams in the experimental group, labeled AI group, will solve a design task using a generative AI. They will be encouraged to use ChatGPT during

the conceptual design. The comparison group, labeled Non-AI group, will conduct the design task without using AI and computers The Non-AI design teams will solve the design task without using AI.

Participants
The study participants are enrolled in the Bachelor of Science in Technology Teacher Education Program at the college. The majority of participants are freshmen or sophomores. While some have design skills, most have little or no experience in design. Participants may have experience with generative AI like ChatGPT or Gemani, but at the baseline, all students will receive instruction on using effective generative AI in the design process before undertaking the task. This study will be approved by the IRB, and student participants will sign an IRB consent form. Participation is voluntary and does not affect their credits; no penalties will be given for non-participation.

Data Collections
To gather data, this study primarily employs the think-aloud protocol. Participants will be assigned a design task and work in groups of three to solve the problem. They will be asked to verbalize their thoughts or express ideas through sketching during the activity, which are recorded on a tape recorder, and the observed sketch data will be collected for data analysis.

Design Task
Participants will be given a design task related to the Design and Drafting course. This will be a conceptual design project, and the outcome will be designed in CAD software and printed using a 3D printer. The design task will include an overview, design criteria, and constraints. The design task will be presented at the presentation.

Data Analysis
The research data will be analyzed using Benami and Jin's (2002) creative conceptual design model. Verbal data gathered through think-aloud protocols will be transcribed and examined to explore the utilization of cognitive processes, design operations, and design entities in a time sequence. Additionally, sketches created by participants will be used in the analysis.

Anticipated Outcomes and Discussion.
This exploratory study will investigate and compare the cognitive processes involved in design between groups that utilized generative AI in their design thinking and those that did not. Firstly, this study will compare the time percentage of design cognitive behaviors shown by teams belonging to AI and Non-AI groups. It will identify which design cognitive characteristics are shown in teams utilizing AI. In addition, this study will conduct a sequential analysis of design cognition to identify sequential patterns of design entities, cognitive processes, and design operations.

Design researchers have presented numerous design process models, often providing procedural models such as problem definition, data collection, analysis, idea generation, selection, modeling, and evaluation as a methodology for problem solving (AUTHOR; Dym & Brown, 2012). Previous research indicates that these stages are not strictly sequential; instead, they often recur in patterns (Clarkson & Eckert, 2004). AUTHOR (YEAR) has shown that stages like

problem definition, analysis, questioning, and modeling tend to repeat, frequently following specific local patterns. Jin & Chusilp (2006) also demonstrated in a conceptual design study that designers tend to go through a cyclical process of problem definition, analysis, idea exploration, concept design, and evaluation. They found that more experienced designers cycle more frequently through evaluation and concept design while less utilizing ideation and analysis. In this study, it is expected that the cognitive process of participants who did not use AI will use the typical sequential cognitive process associated with general design thinking, while those who used gen AI will spend more time and repetitions on evaluation and concept generation.

In terms of design cognition, design thinking shares similarities with learning and architectures of Gen AI. For example, deep learning has several learning approaches, and unsupervised learning resembles the How Might Be (HMW) technique in design thinking because it involves creating gaps in completed text, asking AI to make predictions, and then providing the correct answer. Creatively, the How Might Be technique differs by having no correct answer, but it is similar in that creativity can emerge from a mix of imitation, analysis, and intuition. While various decision-making techniques exist in design thinking, ideas are typically selected through classification, labeling, and weighted comparison methods. Similarly, Gen AI learns by classifying and characterizing data through these same processes.

Creativity was considered one of the most valuable human capabilities and a trait unique to humans (Plucker, 2021). It involves generating something new, original, and useful, which results from recalling, integrating, and synthesizing information obtained through experiences and education. As generative AI has advanced to imitate human thinking, it now enables the creation of novel outcomes that previously did not exist, using probability and complex computing algorithms. There is ongoing debate about whether AI's creations are truly creative and it reduces human attribution to creativity (Vigeant, 2024) . However, it has been widely agreed that AI will extend humans' creativity and critical thinking capabilities when used appropriately and effectively (Creely, Henriksen, & Henderson, 2023; Pandy, Pugazhenthi, & Murugan, 2025). This study aims to broaden the conversation on how to use AI effectively by examining the changes in thinking prompted by AI in design thinking.

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AUTHORS (YEAR)

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Teachers as mediators between communities of practice: Empowering students for the future

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Abstract

In an ever-changing world, it is difficult to predict which engineering skills and competences will be most in demand in the future. What we do know is that the teacher will play a major role in teaching them. In Sweden, many of the technology teachers at upper secondary school level are former engineers who have chosen to become teachers. Previously Étienne Wenger's Communities of Practice (CoP) framework was used to show how teachers' perceptions of the engineering profession influence the teaching of technology subjects. In a community of practice, interaction between members who share goals, engagement and resources leads to learning and competence development. This study extends the previous analysis by examining the role of teachers as mediators of engineering ideals. The teachers interviewed are full members of their educational communities and peripheral members of their former engineering communities. However, they still operate within the boundaries and are committed to keeping the link between the two communities active. In this way, they provide opportunities for their students to become aspiring members of the engineering community. The findings show that there is value for the interviewees in acting on the boundary between the communities, not only to enrich the educational community, but also as a way of manifesting their own identity and competence. The contribution of this study to education in general, and to technology education in particular, is to show how experiences from previous communities of practice influence the teachers' identity, competence and teaching strategies.

Key Words: Engineering education, Upper secondary school, Communities of Practice, Competence, Identity

1. INTRODUCTION

Like many other countries, Sweden advocates STEM education to develop students' interest in technology and science (e.g. Scientix, n.d.; Australian Curriculum, 2024; UNESCO, n.d.). Students interested in STEM subjects are seen as important for Sweden's success in engineering, technology, innovation and entrepreneurship (Government Offices of Sweden, 2025). However, engineering is not a school subject in Sweden (Skolverket, 2024). Without official guidelines, it can be difficult to envisage a teacher who is suitable to teach engineering in schools. Carberry et al. (2023) emphasise that teachers can all contribute to engineering education in schools by

drawing on their diverse experiences. However, many feel unqualified due to a lack of training opportunities (Pearson, 2016). To address this issue, Carberry et al. (2023) recommend that non-engineers undertake professional development, which should include hands-on design practice, pedagogical development, curriculum reflection and community engagement. Meanwhile, some Swedish teachers are former engineers who have undergone short bridging programmes to qualify to teach at secondary level (Lundstedt & Odelberg, 2023). These teachers can contribute valuable industry experience and technical expertise.

This is the second of two studies based on interviews with upper secondary school teachers with an engineering background. Both studies use Étienne Wenger's (1998) *Communities of Practice* (CoP) as their theoretical framework. The studies will henceforth be referred to as the first and second studies. The first study examined how previous engineering experience influences teaching practice (Persson & Norström, 2025). In this second study, the framework is used to examine the role of teachers as mediators of engineering ideals and to explore concepts such as competence and identity.

The following research questions are to be answered by this study:

- How do teachers with an engineering background construct their professional identity within educational communities of practice?
- How is professional identity negotiated in relation to prior participation in engineering communities of practice?

2. LITERATURE REVIEW

Communities of practice

Two fundamental concepts of the CoP theory are *practice* and *community*. The practice of the interviewees is defined based on their own statements, using the CoP theory as a theoretical lens and analytical tool. Their practice involves students, colleagues, teaching materials and course plans, as well as relationships, aspirations and frustrations, among other things. However, for a practice to be defined as a community, certain characteristics must be met. Wenger (1998) describes three such characteristics or, dimensions: *mutual engagement*, *joint enterprise*, and *shared repertoire*. Participants must be united by mutual engagement for a shared goal or enterprise. Hence, *mutual engagement* drives the *joint enterprise*. Finally, participants must *share a repertoire* of resources, such as specific rules, artefacts, and regulations, in order to fulfil the joint enterprise's goal.

Engineering experience influences teaching

In the first study, Persson and Norström (2025) demonstrate how teachers share ideas and ideals from engineering traditions. They familiarise students with the *shared repertoire* of engineering by modelling the problem-solving processes of engineers in their teaching. Students are trained in modelling and prototyping in line with the design process through collaborative activities such

as teamwork. Keeping up with technological developments is also valued, meaning textbooks quickly become outdated and less useful.

Although the interviewees are part of the education community, they have strong links to the engineering community. Teaching is often based on the interviewees' own experiences of the engineering profession and engineering education. They adapt their teaching to their students' interests in order to foster *mutual engagement* in the *joint enterprise* of engineering, as an engineering mind set is beneficial regardless of the chosen career path. However, the demands of the curriculum and the interviewees' view of learning engineering do not always align, which can lead to frustration. In their efforts to teach their approach to engineering, they act as mediators or *brokers* (Wenger, 1998) between the engineering and education communities.

Identity formation

Identity formation is the process by which an individual interprets and reshapes their self-image in relation to other people and the surrounding world (Beijaard et al., 2004; Hughes et al., 2021). For example, an engineer needs to see themselves in relation to the engineering profession (Ju & Zhu, 2023). Teachers' identities are influenced by experiences from professional practice, as well as their personal background. Thus, the constitution of teacher identity is unclear (Beijaard et al., 2004). Some aspects seem important, such as the subject taught, the relationship with students and interactions with colleagues. Other experiences, such as institutional assignments like curriculum development or after-school tutoring, also play a role (Beijaard et al., 2004; Polizzi et al., 2021). This results in a professional identity comprising sub-identities that may conflict. Beijaard et al. (2004) conclude that teachers do not simply have a professional identity, but use it to create their own teaching culture. In conclusion, teachers' identities are constituted based on personal and community-based experiences, which can be influenced separately (Polizzi et al., 2021).

Studies on identity formation in communities of practice (CoP) employ a variety of approaches to the application of the theory. Gustafson (2010), for example, examined the concept of multiple membership and identified six dimensions of professional identity associated with it. Another study (Kelley et al., 2020) investigated how science and engineering technology teachers collaborated with experts from multiple CoP, which increased their self-efficacy in STEM teaching. Polizzi et al. (2021), on the other hand, viewed teachers' CoP as interconnected networks and used statistical analysis to study identity. According to Wenger's (1998) definition of identity building, we are full members when we feel familiar with the practice, know how to interact with others (*mutuality of engagement*) and can contribute to the goals of the practice (*accountability to an enterprise*). We are familiar with the practice's history, artefacts, and resources, and know how to use them to fulfil the enterprise's goals (*negotiability of a repertoire*). Our competencies have developed in line with the practice's demands, becoming part of our identity. Thus, practice, competence and identity are interlinked.

To fulfil their goals and become full members, new members must adapt both their skills and the ways in which they interact with others in the community of practice. Novice teachers, for example, learn tacit teaching knowledge through interactions with experienced teachers (Polizzi et al., 2021), which is a process involving both learning and identity development.

Wenger (1998) links the development of our identity to trajectories because they connect us with the past, present and future. These trajectories can be directed towards or from a community of practice, or they can span boundaries as *boundary trajectories* (Danielsson et al., 2019; Wenger, 1998). The terms *bridging* and *brokering* refer to activities that facilitate the infusion of influences and new ideas between practices. The nature of such bridging activities can differ between communities of teachers. For instance, maths teachers appear to prioritise fewer, stronger links, whereas science teachers seem to prioritise links to novel resources (Polizzi et al., 2021).

3. METHODOLOGY

Data collection

This study is based on thirteen semi-structured interviews with thirteen male and female teachers who have experience in engineering. All interviewees were informed about the study and their rights and gave their recorded or written consent (Åkerman, 2024). The interviews lasted between 40 and 60 minutes, and were conducted in Swedish. The interviews were recorded, transcribed and translated into English by the author. As there are no registers in Sweden detailing teachers' professional experience, the interviewees were recruited through internet searches and previous contacts. This resulted in a convenience sample.

All of the interviewees worked at Swedish upper secondary schools and had additional experience in engineering education and/or professional engineering, as shown in Table 1 (Persson & Norström, 2025, Table 2). They all taught technology subjects on the three-year Technology Programme, which prepares students for further study. Their teaching experience ranged from one to 20 years. Ten of the interviewees had studied for a Master of Science degree and two for a Bachelor of Science degree. All had attended teacher training programmes, with the majority completing short bridging programmes to complement their validated subject knowledge (Lundstedt & Odelberg, 2023). Three had not completed the engineering programme. Two of these had not completed the teacher training programme either. Consequently, all of the interviewees had experience in both engineering and teaching. Other aspects varied, such as age, teaching experience and qualifications.

Table 1.
Interviewees and their educational backgrounds

T1	MS in engineering physics. PhD in physics. Bridging teacher education programme.
T2	MS in mechanical engineering. Worked as a teacher for a few years and then attended a special teacher programme for people with an academic degrees and experience from work in upper secondary school.
T3	MS in electrical engineering. Bridging teacher education programme.
T4	MS in engineering physics. Worked as a teacher for a few years and then attended a special teacher programme for people with an academic degree and experience from work in upper secondary school.
T5	BS in electrical engineering and computer science. Bridging teacher education programme.
T6	MS in computer science and upper secondary school teacher in technology and mathematics after completing a combined engineering and teacher training programme.
T7	BS in mechanical engineering, specialised in economics, innovation, and design. Bridging teacher education programme.
T8	MS in engineering physics and materials science. Bridging teacher education programme.
T9	BS in construction engineering. MS in industrial design. Bridging teacher education programme.
T10	Not completed MS in vehicle engineering, and MS in upper secondary education.
T11	MS in engineering and in education after completing a combined engineering and teacher training programme.
T12	Not completed MS in engineering and in education (a combined engineering and teacher training programme).
T13	Attended an engineering programme but left during the first year. MS in upper secondary education.

Note. Adapted from Table 2 in "Shaping upper secondary school engineering education: the influence of the engineer-teacher", by H.I. Persson, and P. Norström, 2025, *International Journal of Technology and Design Education,* (https://doi.org/10.1007/s10798-025-10007-0). CC BY.

Analysis method

Each interviewee is an active teacher within the community of practice that they represent. Together, several such communities form a constellation of CoPs, which can provide the basis for an analysis (Persson & Norström, 2025). As the analysis aimed to explore teacher identities, the interviewees' statements were mapped against the three identity indicators proposed by Wenger (1998, pp. 152–153). These indicators are, *mutuality of engagement*, *accountability to an enterprise*, and *negotiability of a repertoire*. In an interview study, it is recommended to stay close to the interviewees' statements (Kvale & Brinkmann, 2014), which was also the intention of the analysis.

A reduced version of the analysis procedure follows. First, the transcriptions were read, and quotes relevant to the aim of the study were identified. In the second step, the quotes were mapped to the identity indicators. In the third step, the content of each identity indicator was read

separately. In the fourth step, each quote was read with a focus on its meaning in the original interview. Quotes that appeared particularly relevant to the purpose of the study were selected. In the fifth and final step, the quotes chosen in step four were organised into themes based on similarities. Thus, the identity indicator was enriched with content aligned with the aim of the study (Table 2). This process of identifying themes was similar to thematic analysis (Braun & Clarke, 2006; Bryman, 2011; Kvale & Brinkmann, 2014).

Table 2.
Examples of mapping quotes to Identity indicators and themes

Quote	Identity indicators	Theme
To be able to work in teams and collaborate is an important part of becoming a technician or an engineer. [Students] need to get out there and be able to collaborate with others and be able to communicate what they've done. What kind of problem are we going to solve, can we solve it together. I think they need to practise such things. (T3)	Mutuality of engagement	Teaching engineering
They've learnt quite a lot along the way before reaching university – and actually gain confidence in their own ability to solve problems. ... that's my main goal in teaching, for them to become good problem solvers.. ... I know that some students won't fully grasp it until they start university or even begin working. Then they realise, 'Ah, so that's what he meant'. (T9)	Accountability to an enterprise	Equipping students for the future
… my head teacher gave me this course, now you'll have [to teach] Construction. I've never studied it. Engineering physics doesn't make you a mechanical engineer …. (T1)	Negotiability of a repertoire	Previous experiences

4. RESULTS

The themes generated from the identity indicator, *mutuality of engagement*, *accountability to an enterprise*, and *negotiability of a repertoire* are presented below.

Mutuality of engagement

In a community of practice, there are expectations regarding how members should engage and interact with each other in order to achieve the practice's goals. Therefore, competence involves applying knowledge in a way that is valued by other members and in line with the practice's norms. As the following quotes demonstrate, the interviewees strive to convey engineering norms to their students. For instance, teacher T3 emphasises the importance of learning to solve problems collaboratively, as this is a key engineering skill.

> To be able to work in teams and collaborate is an important part of becoming a technician or an engineer. [Students] need to get out there and be able to collaborate with others and be able to communicate what they've done. What kind of problem are we going to solve, can we solve it together. I think they need to practise such things. (T3)

Engineering skills are not always easy to acquire. T2 argues that the ability to make engineering assumptions is an important skill for students to develop independently, rather than relying on answers from the teacher.

> I explain that these are engineering assumptions. It's a fairly common concepts, and it's something you really need [to understand]. You have to start from what you know and make the best of it ... I don't give them too many answers. It's an exploratory process, a kind of trial and error – and that's how it often is. Unfortunately, there aren't ready-made answers for everything. (T2)

In summary, these statements focus on engaging students in engineering. These statements belong to the theme *teaching engineering*.

Accountability to an enterprise

The interviewees act as a link, preparing their students to participate in the engineering community by equipping them with the necessary skills and abilities. Interviewee T9 is confident that the skills acquired in class will be useful and relevant in the future, even if students initially failed to see how they are connected to engineering.

> They've learnt quite a lot along the way before reaching university – and actually gain confidence in their own ability to solve problems. ... that's my main goal in teaching, for them to become good problem solvers.. ... I know that some students won't fully grasp it until they start university or even begin working. Then they realise, 'Ah, so that's what he meant'. (T9)

The interviewees are aware that not all students will become engineers. However, adopting an engineer's perspective is a way of viewing the world that goes beyond professional life.

> ...we started talking about the phrase knowledge is power, and of course I threw in the question: OK, but is technological knowledge power? I asked that to get them thinking—what does it actually mean for them to understand technology in the future?

> Because if they do, then they'll be able to influence how technology develops or even what kinds of technology are created. What they know will shape things, because they are the future. I really like this way of thinking—of opening things up a bit for their future. (T12)

In summary, these statements discuss how learning goals can provide students with valuable insights that will benefit them in the future. These statements belong to the theme *equipping students for the future*.

Negotiability of a repertoire

A teacher's repertoire of teaching resources is inspired by their previous experiences, such as their professional or educational affiliations. For example, T12 designs teaching activities based on their personal interest in human-computer interaction rather than curriculum requirements.

> What I really enjoyed at [a technical university] … was actually … human-computer interaction. … So I fell back on that when I designed a project with the students, in Technology 2 [a course]. … I mean, I can link it both to the core content and the learning objectives, but it's not something that's explicitly stated as required … It was just something I was passionate about and found easy to build my course around. (T12)

This quotation illustrates how the interviewee had to deal with the demands of the head teacher, who represents the school's formal rules and norms. T1, who studied engineering physics, felt unqualified to teach the Construction course because they are not a mechanical engineer. The Construction course belongs to a different domain of knowledge.

> … my head teacher gave me this course, now you'll have [to teach] Construction. I've never studied it. Engineering physics doesn't make you a mechanical engineer …. (T1)

In summary, these statements concern the organisation of teaching based on previous work and educational experiences. These statements belong to the theme *previous experiences*.

5. DISCUSSION

The teachers interviewed were previously identified as *brokers* between the CoPs in education and engineering (Persson & Norström, 2025). This study examines the interviewees in light of Wenger's (1998) ideas that practice, competence and identity are interconnected.

The theme of *previous experiences* is about the interviewees' references to their past. The interviewees clearly identify with their previous experience in engineering and their personal interests. Rather than basing arguments about teaching qualifications on curriculum requirements, they base them on their engineering background. For example, T1, who holds a degree in engineering physics, objects to the head teacher's request that they teach construction, arguing that it falls outside their area of expertise. A degree in mechanical engineering would be the relevant qualification. However, the head teacher does not seem to view the differences between

degrees as obstacles. The interviewees' personal views of engineering and technology conflict with prevailing educational norms.

Competence in a community of practice is not only about possessing the right knowledge and skills, but also about acting in ways that the community accepts as valid in order to achieve its goals. The theme of *teaching engineering* concerns the present situation of the interviewees. They strive to evoke interest in engineering and train their students in important engineering skills, such as problem solving in teams and making engineering assumptions.

The theme of *equipping students for the future* is about equipping students with engineering knowledge for the future. There are at least two aspects of engineering that the interviewees want their students to understand and achieve. One is mastering essential engineering skills to prepare for further education or employment. The other is that knowledge of technology and engineering is valuable because technology and engineering can change society for better or worse. Possessing this knowledge gives one power. T12 expresses this idea when they say, "What they know will shape things, because they are the future."

The teacher identities described in this study are similar to those described by Beijaard et al. (2004). Although the interviewees' primary professional identity is that of a teacher, they retain links to the engineering profession in the form of sub-identities. These sub-identities may conflict with the norms of the educational community. However, the interviewees demonstrate an ability to cross boundaries and enrich their teacher identity with influences from their previous CoPs. Although they appear to be more committed to engineering ideals than educational ones, their goal is to guide their students towards the future, ideally onto an engineering trajectory (Danielsson et al., 2019; Wenger, 1998). Overall, in line with Beijaard et al. (2004), the interviewees demonstrate that they use their professional teacher identity to create their own teaching culture.

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Promote technology learning using a spiral curriculum – Developing evidence-based concepts for technology education focusing on problem-solving

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Abstract

Due to digitalization, children are influenced by the development of technology and use technology to solve problems. Addressing the associated competencies in early learning processes is essential for responsible participation in society (Gervé, 2022). One approach is the promotion of computational thinking (Wing, 2006), which expands established problem-solving skills to include digital aspects.

National and international empirical studies have demonstrated that, both general problem-solving and specifically in relation to computational thinking, students' competencies must be fostered to ensure successful participation (e.g. Bohrmann, 2017; Eickelmann et al., 2024). Initial responses include, for instance, the mandatory implementation of informatics education or STEAM education already at the early childhood and primary levels (OME, n.d.; MSB NRW, 2021). Furthermore, studies reveal that spiral curricular learning approaches offer potential for continuous learning (Ringelberg, 2017).

However, inclusive, spiral curricular concepts for technology learning in the context of mechanical and digital controlling-processes seem to be insufficiently explored empirically. Therefore, this research project investigates the following questions: a) How can spiral-curricular technology education focusing on problem solving be designed?; b) To what extent do these concepts promote competency development? The quasi-longitudinal study uses a pre-post-design, in which the promotion of technology education in the context of mechanical and digitally-supported controlling-processes is assessed at various educational transitions. An intervention promoting unplugged programming as well as programming with the BlueBot™ and the microcontroller Calliope mini is tailored to each educational level between the measurement points.

This article presents the two test instruments used and shows initial quantitative results from a pilot study of pupils aged 8 to 11 years (N=62). It discusses the instruments for future use against a descriptive and inferential statistical evaluation.

Computational Thinking, Inclusive Education, Spiral-curriculum, Technology Development

1. INITIAL SITUATION

Technology is omnipresent and influences many domains. In contrast to nature, which is causally aligned, final-aligned technology refers to man-made systems and artifacts (material technology) designed to satisfy human needs by using science. Furthermore, the production and use of artifacts are included (socio-technology) (DGTB, 2018; Graube & Mammes, 2013). Increasing digitalization and digitality (Irion et al., 2023), new scientific findings and needs are expanding mechanical material- and socio-technology and controlling-processes by integrating electronic impulses for digitally-supported controlling-processes (Gervé, 2022; Tenberge et al., 2024a).

Even at preschool age, children discover technology by constructing, using and evaluating it (Möller & Wyssen, 2018). They also discover digital extensions of controlling-processes. However, there is no insight into artifacts and processes and no understanding of functionality (Mammes et al., 2022). This legitimizes the educationally effective promotion of skills in mechanical and digitally-supported controlling-processes from the elementary level onwards to promote technological literacy (Bergner et al., 2018; Schemel et al., in press).

2. TECHNOLOGY EDUCATION IN A CHANGING LIVING ENVIRONMENT

The aims of technology education include developing technological knowledge and ways of thinking, working, and acting (e.g. “constructing and producing”) (GDSU, 2013) to understand, invent, design and evaluate technology. These competencies foster a critical attitude toward technology and support responsible participation (Mammes et al., 2022).

Problem orientation is the main concept of technology education with everyday problems relevant to children serving as starting points for promoting subject-specific and procedural knowledge. Authentic, relevant and exemplary problems encourage active and constructive engagement (Beinbrech, 2022). Problem-oriented technology education can address problems on a content and methodological level. If learning is based on problems, the problem itself becomes the subject matter (Tenberge et al., 2024a). The content knowledge acquired can be transferred to other situations and problems (Einsiedler, 1994). On a methodological level, the focus is on learning to solve problems and on the process structure of problem-solving, often described through circular models (e.g. Ahlgrimm et al., 2018; Mammes et al., 2022). Open problem designs promote various solutions, approaches and strategies, while defined criteria guide targeted solutions and enable evaluation and optimization.

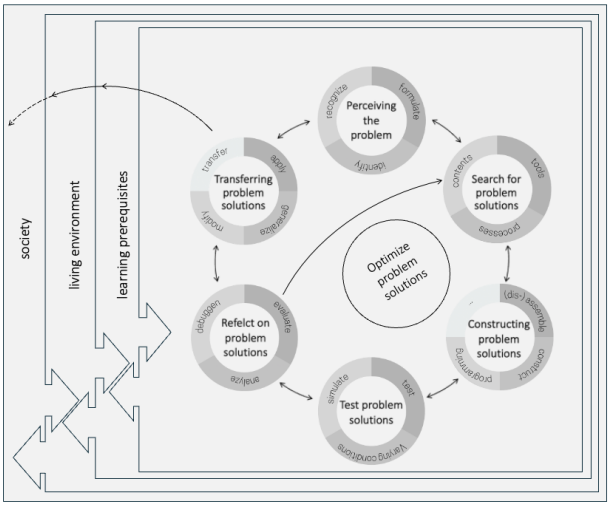
As digitalization expands mechanical technologies and controlling-processes, problem-solving learning must also evolve. This includes new content-related aspects of technology problem-solving (e.g. “How can a robotic vacuum cleaner be programmed so that it minimizes energy consumption?”) and additional methodological aspects. One possible addition could be computational thinking (CT), an analytical thinking competence for solving problems effectively and efficiently using mathematical, technical, informatic and scientific thinking, expressed in analogue or digital ways understandable by humans or computers (Boom et al., 2018; Romeike, 2017; Tsarava et al., 2022; Wing, 2008). CT is not a competence used only by computer scientists; it is also applied in everyday situations (Wing, 2006), drawing on sub-skills such as abstraction,

algorithmic thinking, and debugging (Barr & Stephenson, 2011; Romeike, 2017; Tsarava et al., 2022; Wing, 2006). If CT supplements the methodological aspects of problem solving, we must ensure that mechanical controlling skills are not displaced (Schemel et al., in press).

PiCT (Problem-solving integrating CT) could be a way of methodically addressing technology education by taking up the problem-solving process of mechanical and digital-supported controlling-processes.

Figure 1.

Model of PiCT problem-solving (Schemel, in press)



As a synthesis of technology problem-solving and CT, PiCT integrates basic problem-solving steps in the inner circle (Mammes et al., 2022; Tenberge, 2024; Wing, 2008). Competencies such as “perceiving the problem” or “searching for problem solutions” follow an iterative cycle. Transitions between the sub-steps are possible, e.g., developing a potential solution may reveal its infeasibility, prompting a return to the solution-search phase. Testing a problem solution leads to reflection and, if needed, to optimizations, which can be repeated as often as necessary. Both the solution and the problem-solving process can be transferred to other problems.

The model explicitly emphasizes the reciprocal influences of society, living environment and learning prerequisites on the problem-solving process. For example, good pattern recognition (a learning prerequisite) supports the problem-solving process because patterns can be more easily recognized in the available data.

PiCT addresses mechanical and digital-supported aspects of problem-solving. The outer circles describe exemplary actions linked to specific sub-competencies, targeting mechanical and digital

controlling-processes. PiCT encompasses mechanical tools (e.g. hammers) and digital tools (e.g. microcontrollers or programming environments). The actions involved are likewise mechanical and digital, enabling PiCT to address a wide range of problems—from purely mechanical (e.g. designing vehicle lighting) to purely digital (e.g. debugging code) and digital and mechanically connected problems (e.g. developing sensor-controlled lighting to conserve battery power).

3. SPIRAL-CURRICULAR TECHNOLOGY EDUCATION

It remains to be clarified how technology education can be effectively established across educational levels to promote a confident, self-determined, and safe approach. Children grow up in a digitalized and technologized world. Mere exposure to mechanical and digital control processes does not ensure competent use; responsible application requires deeper understanding (Bergner et al., 2018; Tenberge et al., 2024b). Experiences at the elementary level are crucial for developing content- and process-understanding, interest, self-efficacy and reflective use of mechanical and digital controlling process. Increasing digitalization and digitality emphasize the need to embed digital technology competencies in primary education, as the confident and competent handling of data and algorithms. This includes abilities such as information search, assessment, critical evaluation (Schumann, 2021) and dealing with AI tools (OECD, 2019). A digitally and mechanically integrated technology education at elementary and primary levels supports later specialization in secondary education, where technology is addressed in differentiated subjects (OME, n.d.; MSB NRW, 2021).

As Irion et al. (2023) emphasize, curricula must evolve in response to growing digitalization. Internationally, demands such as these are responded to, for example, through the mandatory implementation of computer science and technical education (OME, n.d.; MSB NRW, 2021).

A spiral curriculum integrating technology in the context of mechanical and digital control offers a potential approach to developing competencies across educational levels. By introducing topics at a basic level and resume them with increasing complexity, a spiral curriculum supports the development of cognitive skills (Bruner, 1976). This progression enables the promotion of subject-specific, interdisciplinary skills and ways of thinking and working appropriate to each educational level (Hardy et al., 2017). The subject can also be addressed in different forms of representation, creating different approaches and simplifying the transition to further educational levels (Leuchter et al., 2021; Simon, 2015). Chapter 5 outlines how such a spiral curriculum can be implemented.

4. PROBLEM OUTLINE

Although technology education is relevant for various reasons already outlined, empirical findings are often missing. Some studies provide empirical results on the differentiated interests and self-concepts (Mammes et al., 2022) or analyze concepts on various subjects (Biester, 1991; Möller & Wyssen, 2018). A few studies show that children can solve complex problems (Beinbrech, 2003; Möller, 1991). Bohrman (2017) shows that the problem-solving skills of pupils assessed using the Tower of London test (ToL) are significantly below the arithmetic mean (Bohrmann, 2017) and should be promoted. Furthermore, cross-sectional studies that address sub-

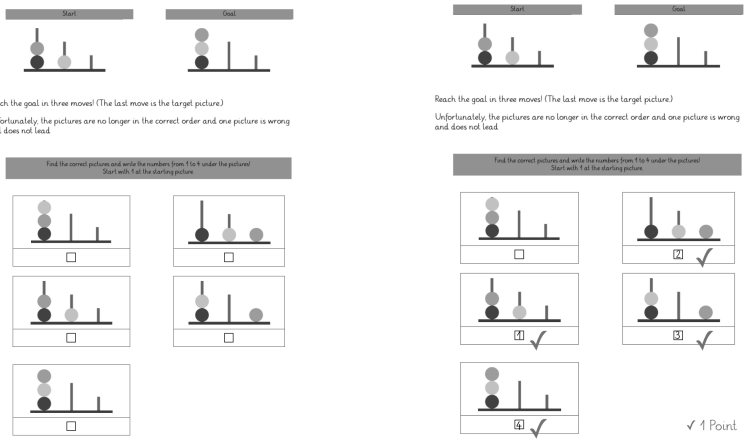
areas of technology education such as “forces and balance” (Leuchter et al., 2021) show that a spiral-curricular development of skills can be conducive to learning (Meudt et al., 2017). Specifically for digitally enhanced, technology-related areas, international studies show that children use digital technology artifacts daily. Furthermore, the self-assessment of technology skills shows that support is needed (mpfs, 2024; Schmid et al., 2025). The ICILS studies show similar results. CT sub- studies of the ICILS indicate that eighth-grade students' skills are only basic. (Eickelmann et al., 2024).

Despite initial empirical studies, there are still no studies that a) focus on the spiral-curricular promotion of technology education in the context of mechanical and digital-supported controlling-processes and show changes in children's competencies at different educational-levels, and b) evolve evidence-based concepts for the competence development.

5. METHODS AND PROCEDURES

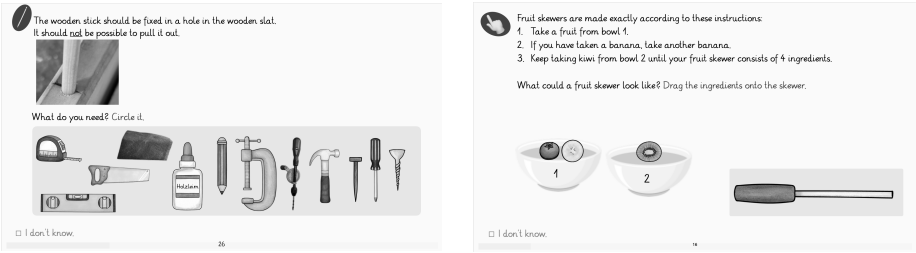
The project addresses this desideratum and a) develops a learning environment to promoting PiCT along a spiral-curriculum and b) develops an instrument to assess PiCT. In a quasi-longitudinal study, the problem-solving-skills at the transitions between educational-levels are to be examined using mixed-methods in a pre-post design. PiCT as a sub-area of the study is assessed using an established paper-pencil-test for the context-independent assessment of problem-solving (ToL by Bohrmann, 2017). The ToL includes five tasks; each task can score one point. Participants must order images representing steps in a sequence to achieve a final arrangement of three colored balls, minimizing movements. To ensure group compatibility, no physical model is used.

Figure 2.
Example-item ToL and Example of a solution (Bohrmann, 2017, S. 342; translated by Schemel (2025))



The learning progress regarding PiCT is assessed using the digital questionnaire CleeverTechPRO, developed by the author for use on tablets with primary school students. It captures PiCT competencies across differentiated contexts and comprises 15 open-ended and 52 closed-ended items. The open-ended responses were analyzed using qualitative content analysis but are not included in the subsequent evaluation. A descriptive and inferential statistical analysis is conducted for the closed-ended items (Chapter 6). Each correctly answered item is awarded one point, yielding a total possible score between 0 and 52.

Figure 3.
Example-items CleeverTechPRO (Schemel, 2025)



These translated task examples illustrate that the questionnaire targets technology-related skills in mechanical and digitally-supported controlling-processes.

Between the measurement points, an intervention was implemented to promote problem-solving skills through these processes. In several preliminary projects, the tasks were iteratively evaluated and refined following the design-based research approach (Euler, 2014; Schröer & Tenberge, 2023; Tenberge et al., 2024a; Tenberge et al., 2024b). Structuring strategies — such as reducing complexity via sub-problems (Möller et al., 2006) — were integrated within a spiral curriculum.

The spiral curricular intervention begins with an introduction to the importance of unambiguous commands. Students give each other instructions to navigate a maze (Figure 4.1). Then, they solve increasingly complex tasks with the programmable robot BlueBot™ (Figure 4.2), such as identifying **a** path, identifying **all** possible paths, or finding a path that **fulfils a criteria** (e.g. the fastest). During this intervention, the BlueBot™ was used as a bus to bring the children to different fairground attractions and complete various tasks in this setting. One attraction was the game "Hot Wire", which was built by the students themselves and, in grade 3, was programmed in a block-based environment using the Calliope mini to prevent cheating in the game (Figure 4.3) (Kirste & Pelz, 2024; Tenberge & Rogoll, 2024). Through these activities, students acquire fundamental concepts such as the input–processing–output principle, which provides the basis for further programming activities.

Figure 4.
Insight into the spiral curricular intervention (Schemel, 2025)

6. FINDINGS

A pilot study was conducted with (N=62); divided into three classes (n=27 third graders (two classes); n=35 fourth graders). The test instruments described were used in a pre–post design and analyzed statistically.

6.1. Promotion of Problem-Solving Skills

Table 1.
Descriptive findings for Problemsolving-Skills

	Pre-Test (Max.=5; Min.=0)	Post-Test (Max.=5; Min.=0)
Total (N=62)	M= 2.71 SD= 1.68 α= .730	M= 2.85 SD= 1.68 α= .726
$Class_1$ (n=27 third graders)	M= 3.15 SD= 1.61 α= .686	M= 3.0 SD= 1.21 α= .431
$Class_2$ (n=18 fourth graders)	M= 2.5 SD= 1.54 α= .783	M= 2.94 SD= 1.76 α= .645
$Class_3$ (n=17 fourth graders)	M= 2.24 SD= 1.86 α= .873	M= 2.52 SD= 2.03 α= .831

The score for problem-solving skills increased from a mean slightly above the scale midpoint in the pretest *(M=2.71)* to a value slightly above it in the post-test *(M=2.85)*. The change in competence ranged from -3 to 3 points. No change in competence was shown by n=13 children. Furthermore, a t-test with a paired sample was calculated: $t(61)=-.745, p=.459$ (two-sided). No significant difference was found (one-sided p: p=.230; two-sided p=.459). The 95%-confidence interval for the mean difference ranged from -0.54 to 0.25. The calculation of the effect size (Cohen's d) is -0.1, indicating a small effect.

A differentiated analysis shows that Class1 has the highest problem-solving skills in the pre-test *(M=3.15)* and post-test *(M=3.0),* though their skills decline slightly. Class2 starts at the scale midpoint *(M=2.5)* and improves by 0.44 points *(M=2.94).* Class3 has the lowest scores overall but also shows improvement from the pre-test *(M=2.24)* to the post-test *(M=2.52).*

6.2. Promotion of PiCT-Problemsolving

PiCT-skills were assessed using *CleeverTechPRO* (N=60).

Table 2.
Descriptive findings for CleeverTechPRO

	Pre-Test	**Post-Test**
CleeverTechPRO (total) (52 closed-ended response items; 14 open-ended response items)	M= 4.82 Min.= 1; Max.= 11 SD= 2.19	M= 6.32 Min.= 0; Max.= 16 SD= 3.53
Perceiving the problem (7 closed-ended response items; 7 open-ended response items)	M= 1.27 Min.= 0; Max.= 3 SD= .58	M= 1.62 Min.= 0; Max.= 5 SD= 1.19
Search for problem solutions (3 closed-ended response items)	M= 0.56 Min.= 0; Max.= 2 SD= 0.56	M= 0.55 Min.= 0; Max.= 2 SD= 0.59
Constructing problem solutions (32 closed-ended response items)	M= 2.12 Min.= 0; Max.= 5 SD= 1.30	M= 3.03 Min.= 0; Max.= 8 SD= 1.93
Reflect on problem solutions (10 closed-ended response items)	M= 1.24 Min.= 0; Max.= 3 SD= 0.73	M= 1.59 Min.= 0; Max.= 5 SD= 1.03
Test problem solutions (4 open-ended response items)	Qualitative evaluation only	
Transferring problem solutions (4 open-ended response items)	Qualitative evaluation only	

The score for CleeverTechPRO increased from a mean markedly below the average in the pretest *(M=4.82; Max.=52; Min=0; SD=2.190)* to a value slightly above in the post-test *(M=6.32; Max.=52; Min=0; SD=3.534)*. The children responded to an average of 10.47 items *(SD=4.873)* in the pre-test. Due to the small number of items processed, no reliability analysis can be carried out. A comparison of the average number of correctly completed items with the number of completed items shows that ~46% of the tasks were answered correctly. In the post-test they completed an average of 18.13 items *(SD=6.703)*, or ~35%. The change in competence is between -4 and 8 points. No change in competence is shown by 6 children. An evaluation of the sub-competencies shows that a tendency towards an increase in competence can be demonstrated in almost all sub-competencies.

A t-test with a paired sample (n=60) was calculated*: t(59)=-5.120,p=<.001*. A significant difference was found (one-sided and two-sided p=<.001). The 95% confidence interval lies

between -2.29 and -1.01 and indicates a significant change. The effect size (Cohen's d) is -0.66, indicating a medium to large effect.

Table 3.
Descriptive statistics of the CleeverTechPro (total), stratified by class

	CleeverTechPRO (total)	
	Pre-Test (Max.=52; Min.=0)	Post-Test (Max.=52; Min.=0)
Total (N=62)	M= 4.82 Min.= 1; Max.= 11 SD= 2.19	M= 6.32 Min.= 0; Max.= 16 SD= 3.53
Class 1 (n=27 third graders)	M= 4.19 Min.= 1; Max.= 10 SD= 2.26	M= 5.62 Min.= 0; Max.= 11 SD= 2.98
Class 2 (n=18 fourth graders)	M= 5.28 Min.= 3; Max.= 8 SD= 1.63	M= 7.78 Min.= 1; Max.= 16 SD= 4.01
Class 3 (n=17 fourth graders)	M= 5.31 Min.= 2; Max.= 11 SD= 2.47	M= 6.37 Min.= 1; Max.= 12 SD= 3.42

The class-specific analysis reveals differences in initial performance levels and learning gains. In Class1, the mean score increased from *M=4.19* to *M=5.62*, indicating a gain of 1.43 points, accompanied by a slight increase in standard deviation. Class2 showed the largest improvement, with scores rising from *M=5.28* to *M=7.78*, accompanied by a substantial increase in score dispersion, indicating greater heterogeneity in the post-test. In Class3, the mean increased from *M=5.31 to M=6.37*, again with a slight increase in variability.

6.3. Correlation between CleeverTechPRO and ToL

A rank correlation (Spearman) was carried out to examine the correlation between the changes in competence. This included n=57 paired values. The Spearman coefficient was selected as a normal distribution can only be assumed for the CleeverTechPRO *(Shapiro-Wilk $_{CleeverTechPRO}$:p=0.20; Shapiro-Wilk$_{ToL}$:p=0.025)*. The rank correlation shows a negative, but weak and not significant correlation *(Spearman-Rho=-0.171;p=0.202,n=57)*.

7. DISCUSSION AND OUTLOOK

7.1. Suitability of the Test Instruments for the Study

The results serve to evaluate the instruments. The ToL-test shows no statistically significant results. Striking are the class-related differences, particularly the decline in competence in Class1, despite the uniform intervention. A possible explanation, which includes the specific cohort, is the high number of students in Class1, which may have hindered individual support for problem-solving skills. Another possible explanation, based on the test instrument, is the nonspecific design of the content.

In contrast, the CleeverTechPRO indicates a statistically significant increase in PiCT, suggesting that the intervention specifically promotes PiCT rather than general problem-solving skills. This assumption is supported by the lack of systematic correlations (Chapter 6.3). The results (Chapter 6) imply that the CleeverTechPRO may be more aligned with the research focus, as it likely assesses the competencies promoted.

The class-differentiated analysis indicates that students in Class1 achieved lower outcomes. One explanation may be that fourth-grade students (Class2 and Class3) had more prior exposure to PiCT-related learning or greater experience with tablet use—though this remains a methodological limitation that requires further investigation. A follow-up test with a larger sample is recommended to confirm the reliability of the results.

The CleeverTechPRO evaluation reveals low item completion, potentially due to challenges in handling digital tools and item complexity. Our observations indicate that tablet-based work is highly motivating. A wide range of tasks (e.g. showing videos) and support formats (e.g. read-aloud function) offer potential for the differentiated PiCT assessment, even in inclusive settings. However, competent use of tablets and digital pens appears to be a prerequisite. Maybe the preceding sample items are not sufficient; thus, potential test-retest effects should be discussed in future research. The cause of the observed decline in competence remains unclear; possible factors include demotivation or test unreliability. Follow-up interviews are intended to provide insights, including perceived task complexity, to support future test adaptations.

7.2. Development of a spiral curriculum: Adaptation of the intervention-design

We outlined the curricular sub-area for primary education, but, within a spiral curriculum, skills can already be established at the elementary level. With analogue programming tasks (e.g. navigating a person through a labyrinth), children learn the importance of unambiguous commands, experience that identical commands under the same conditions always lead to the same result and the everyday occurrence of algorithms (Bohrmann & Tenberge, 2024). Subsequently, the introduction to the BlueBot™ can follow. Due to the range of task complexities it supports, the BlueBot™ is suitable for early childhood education and can be further utilized in primary school. The above-described tasks for primary education can be followed by more complex programming tasks of sensor-controlled systems, e.g., programming an alarm system using an acceleration sensor (Vehmeier, 2024). Mechanical and digitally supported control processes can be combined, requiring students to find mechanical solutions for attaching digital components to ensure proper sensor alignment. Finally, these skills can form the basis for complex, text-based programming, e.g., in Phython at lower secondary level.

Results from the primary school intervention show increased standard deviation across all classes, indicating varying levels of individual progress. Therefore—likely relevant across educational levels—future implementations should more precisely address heterogeneous prerequisites, e.g., individual scaffolding measures to support PiCT-skill development.

7.3. Further studies

Further pilot studies should evaluate whether the ToL is suitable for assessing problem-solving skills in mechanical and digitally-supported controlling-processes. Norm tables of the original ToL, on which Bohrmann´s version (2017) is based, indicate high task complexity (Tucha & Lange, 2004). Therefore, i) results may be cohort-dependent and ii) the appropriate educational levels for applying the ToL must be determined. Adaptations in task representation, e.g., by using models, can also be considered and evaluated. In this context, potential indicators of competence decline must be clarified. One initial assumption is decreased motivation due to perceived difficulty during the pre-test.

Additional pilot studies will also examine adapted interventions and research designs at the elementary, primary and secondary levels. For future cycles, using a control group is necessary to measure learning effects from the tests and account for other external factors.

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Technological education: Strengths and constraints experienced by public education stakeholders in Quebec, Canada

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Abstract

This research explores the state of technological and engineering education in Québec, within the context of implementing current science and technology reform curricula. It highlights the challenges and opportunities faced by educators in diverse contexts, including Indigenous, English, and French sectors, as well as adult education. The study examines the successes and challenges experienced by educators in delivering technology and engineering instruction, as well as the discourse on equitable access to technology and engineering education, which highlights the importance of inclusive pedagogy and curriculum renewal. We draw on Lipsky's (2010) theory of street-level bureaucracy where public service workers, including teachers, act as key agents in policy implementation within hierarchical authority organizations. Findings underscore the need for curricula that align with both teachers' and learners' experiences. Moreover, culturally relevant evaluation tools, particularly for teachers in Indigenous communities and adult education are crucially important. By focusing on these diverse contexts, this study examines the needs and perspectives of educators working with underrepresented groups and in mainstream educational settings. Questionnaires and semi-structured interviews with in-service science teachers, lab technicians, and science consultants were collected and analyszd. Findings suggest a lack of institutional support, resources, and equipment, which limited teachers' capacity to deliver effective technology education in schools. Participants reported differing perspectives on whether technology should be integrated into the science curriculum or taught as a separate subject, as well as how to evaluate students in diverse educational contexts. These discussions reflect broader debates about equity in education and the need for strategies that bridge the gap between diverse communities and technological realities. This study contributes to ongoing efforts to develop equitable access to technology education, which should be a priority for classroom practitioners and policymakers.

Key Words Technology Engineering Education, Equity, In-service teachers Quebec Canada

INTRODUCTION

Recent international policy efforts have encouraged school systems to integrate engineering and technology objectives into K-12 education. Like other jurisdictions in North America, Europe, and Australia, the province of Québec, Canada, introduced the Québec Education Program (QEP) to develop technological and engineering literacy among all students in grades 7 to 10 through design-based explorations of systems and processes (Ministère de l'Éducation du Loisir et du Sport, 2007).

In this paper, we distinguish between technology and engineering by framing technology as the artifact, product, or process that emerges from engineering activities to address human needs or improve existing conditions (Guillemette et al., 2011). Engineering, in contrast, can be understood as a systematic and iterative problem-solving process for designing and constructing solutions to human problems (de Vries, 2016). In other words, engineering is the problem-solving process, while technology is the resulting solution. While the Québec curriculum emphasizes technological problem-solving, it rarely explicitly names engineering, despite the presence of engineering principles in its learning progressions. Moreover, the Québec curriculum does guide teachers on what technology is and how it differs from science (Guillemette et al., 2011).

Understanding how science teachers reconcile these pressures can provide critical insight into the implementation gap between policy and practice in STEM education. Our study highlights how teachers, science consultants, and lab technicians collectively and individually interpret, adapt, and enact technology and engineering objectives in diverse school settings.

This paper addresses the following research questions:

1. What challenges do Québec professionals face in teaching technology and engineering, and how are existing resources and materials being used in schools?
2. What forms of professional development are accessible to help Québec teachers develop the necessary skills for delivering technology education?
3. What institutional supports exist for Québec educators at the elementary and secondary levels for delivering technology education?

LITERATURE REVIEW

The lack of clarity in the Québec curriculum has direct implications for classroom practice. Teachers' capacity to integrate engineering and technology objectives depends on teachers' understanding of these terms and their distinction. It is not surprising that many teachers feel underprepared to teach technology and engineering content (Charland et al., 2009; Savard et al., in press), citing a lack of training and access to material resources as key barriers to their implementation. The QEP outlines explicitly STEM objectives in grades 7 to 10. However, integrating technology and engineering objectives into classroom practice remains elusive for many teachers. Implementation challenges are exacerbated by systemic inequities that limit access to STEM education, particularly the continued underrepresentation of Indigenous youth in

post-secondary science streams (Rahm et al., 2019) and regional disparities in school funding and support. This paper explores how Québec science teachers adapt their classroom practices in response to institutional constraints while implementing technological and engineering pedagogies.

We draw on Lipsky's (2010) theory of *street-level bureaucracy* (SLB), which conceptualizes public service workers, including teachers, as key agents in policy implementation. SLBs operate within organizations that are characterized by hierarchical authority structures, institutional norms, limited resources, and conflicting demands. Québec teachers have the right to choose instructional methods, and they are guaranteed professional autonomy to interpret and apply curricular policies based on their judgment and the school's educational project (Loi sur l'instruction publique, 2025). Teachers "are not just mere implementers of policy but instead pivotal actors with much agency (Hall & Hampden-Thompson, 2022). As such, teachers are SLBs. They make decisions, establish routines, and devise creative strategies to navigate policy uncertainties and manage work pressures. In so doing, they "*become* the public policies they carry out." (Lipsky, 2010, p. xiii).

METHODOLOGY

This study employed a qualitative design using semi-structured interviews to explore the structures and conditions that influence educators' enactment of technology and engineering in Québec schools. We drew on critical ethnography (Madison, 2020) to examine how teachers' professional practices were shaped and, at times, constrained by broader ideological and institutional forces, including funding limitations, inequitable resource distribution, and systemic pressures embedded within the education system.

Critical ethnography highlights how institutions reproduce social and structural inequalities while also exploring the agency of individuals and communities to challenge or negotiate these forces. In addition to critical ethnography, we drew conceptually on Lipsky's (2010) theory of street-level bureaucracy to understand how educators function as front-line policy actors. As street-level bureaucrats, educators exercise discretion in the face of resource limitations, policy ambiguity, and institutional constraints, adapting official mandates to local realities. This perspective enabled us to understand how educators' choices and coping strategies influence instructional practices and the enactment of educational policy in classrooms.

This paper reports on Phase 1 and II data from a larger four-phase research project. In phase I**,** 73 participants completed a questionnaire. These included 17 school board science consultants, 37 teachers, and 19 science lab technicians working in elementary, secondary, and adult education. Phase I participants were invited to participate in semi-structured interviews for Phase II.

Phase II included 28 participants: 8 science consultants, 14 teachers, and 6 lab technicians for a total of 56 participants (Table 1). Participants worked in diverse educational contexts, including rural, suburban, urban, and Indigenous communities. They represented Francophone Centres de services scolaires, and Anglophone school boards.

Interviews were conducted via Microsoft Teams and lasted between 30 and 45 minutes. Interview questions explored pedagogical approaches to teaching technology and engineering, with a focus on perceived successes and barriers. Interviews were audio-recorded, transcribed, and organized into datasets for analysis.

Table 1.
Participant profile

Educator	English	French	Average Years' Experience
Teachers	12 ***	25	15.07
Pedagogical Consultants	11	6	15.34
Lab Technicians	16	3	14.37

***Includes 1 Adult education teacher and 1 teacher in an Indigenous School Board

Data analysis employed an abductive thematic approach (Thompson, 2022), involving an iterative process of moving between coded data and theoretical constructs. This process enabled us to refine emerging themes that guided our interpretation, with a focus on the interplay between institutional constraints and professional discretion. Regular team meetings supported analytic credibility by facilitating discussion, resolving discrepancies, and minimizing individual researcher bias. Through this process, we identified cross-cutting themes that illuminated how educators navigate, negotiate, and sometimes resist the institutional conditions shaping science and technology education in Québec.

RESULTS

This section presents our findings through the lens of Lipsky's theory of street-level bureaucracy. Teachers, consultants, and lab technicians respond to institutional constraints with varying forms of agency. Their reflections reveal the tension between curricula policy and the pragmatic adaptations teachers draw upon to make technology and engineering instruction workable in their schools. These adaptations are often shaped by access to material resources, professional development, and the professional autonomy afforded to them by institutional leadership.

Teachers' Pedagogical Strategies and Resource Constraints

Teacher respondents reported using a variety of pedagogical tools to teach the Technological World, including direct instruction, videos, object analysis, and hands-on design projects. However, these practices were often contingent on available resources. All but one high school teacher reported access to tech light tools such as hand saws and power drills. In contrast, access to tech-heavy tools (such as band saws, drill presses, and belt sanders) was uneven. A novice teacher described relying solely on workbooks and sketches, citing a lack of access and training.

These adaptations exemplify what Lipsky (2010) describes as street-level discretion. Street-level bureaucrats exercise authority and agency when they are unable to perform their jobs as prescribed due to the limitations of the work structure. Teachers had the freedom to interpret and

modify curricula policies in response to local realities. Teachers with DIY backgrounds or access to tech-heavy workshops were more likely to engage in tech-heavy instruction. Others avoided these projects due to safety concerns or a lack of expertise. The time spent teaching the Technological World ranged from a few weeks to two months, suggesting the use of coping strategies designed to align instructional choices with institutional and material constraints.

Support from lab technicians was crucial to the implementation of technology. Teachers emphasized that "we couldn't do it without the lab techs," although this support was absent in northern Indigenous communities and adult education settings. This support infrastructure is characteristic of SLB environments where policy implementation relies on interpersonal networks rather than systemic supports.

Systemic Challenges

Teachers identified systemic challenges, including a dearth of project ideas, a lack of safe and relevant materials, time constraints, and limited expertise. One teacher stated, "The curriculum is repetitive and not stimulating to the average student," while another called the material "boring." These sentiments reflect a pattern of superficial compliance, where teachers fulfil curriculum requirements but adapt content to fit what is practically achievable. Requests for professional learning and development (PLD), a bank of project ideas, and updated resources indicate a need for institutional investment.

Teachers' conceptions of technological thinking revealed epistemic fragmentation. Responses ranged from confusion ("I don't know") to instrumental definitions ("solving a problem to make life easier"). This conceptual ambiguity was evident across both English and French sectors, as well as in urban, suburban, and rural institutions. Lack of a coherent conceptualization of technological thinking can hinder the successful implementation of technology and engineering curricula. This absence of a collective understanding mirrors Lipsky’s notion that street-level bureaucrats often develop idiosyncratic interpretations of policy when central guidance is vague.

Lab Technicians as Mediating Agents

Like teachers, lab technicians exercised considerable discretion in shaping technology education. Lab technicians emphasized the developmental value of hands-on learning while lamenting the inadequate facilities and safety code compliance issues. They also spoke extensively of teacher reluctance, lack of time, and limited technical skills as persistent barriers.

Like teachers, lab technicians exercised considerable discretion in shaping engineering and technology education. They emphasized the value of hands-on learning while lamenting inadequate facilities and safety code compliance issues. They also spoke extensively about teacher reluctance, lack of time, and limited technical skills as persistent barriers to implementation.

Consultants: Navigating Gaps in Policy and Practice

Formal teacher training was largely absent. Consultants provided ad hoc PLD based on individual teacher requests. This aligns with Lipsky's notion that policy success is depends on localized discretion and informal resolutions. Consultants noted that while some teachers willingly incorporated engineering and technology lessons into their STEM curricula, others avoided doing so, citing discomfort, disinterest, or a lack of expertise.

Science consultants reported that technology equipment existed, it was unevenly distributed. In some cases, schools were categorized as "tech heavy" or "tech light," with inconsistent maintenance and use of facilities. One consultant described a Raspberry Pi coding initiative that faltered due to staff turnover, exemplifying the fragility of reform efforts when not embedded in stable institutional frameworks.

Consultants highlighted the importance of developing students' technological thinking and design competencies but questioned whether the current curriculum—and the means for implementing it—were adequate. Suggestions included sharing successful projects, increasing access to PLD, and re-evaluating the role of textbooks in promoting learning.

One consultant remarked, "We're not textbook creators, yet teachers are expected to design their own resources without formal training. That expectation is unrealistic." Another warned against pedagogies centred on guided inquiry with novice students, noting that such approaches can increase cognitive load if not appropriately scaffolded. These observations reflect SLB's concern that street-level implementers are burdened with responsibilities without corresponding institutional support.

Student Engagement

Science teachers and consultants reported high student engagement when hands-on projects were integrated into STEM classrooms. Students appreciated seeing their designs "come to life," which underscored the value of including these projects. However, one lab technician suggested the manual skills required for these projects often limited the potential for successful outcomes.

Structural Inequities and Institutional Silence

A science teacher in a northern Indigenous community described a cultural disconnect with the technology portion of the QEP's standardized final exam. Additionally, the lack of engineering and technology materials relevant to students in the community highlighted structural inequities in how policy is implemented across different regions.

Constraints and Adaptations

Lab technicians and science consultants acknowledged the institutional constraints facing teachers. However, their solutions focused on adaptive strategies that highlight the uneven implementation of engineering and technology concepts across the province. Workaround strategies become normalized rather than creating conditions for structural change.

These findings illustrate that the implementation of technology and engineering content in Québec schools is highly variable and shaped by educators' judgments. Teachers, lab technicians, and science consultants act as bureaucrats. Their daily activities are driven by interpreting, adapting, and at times, resisting curricular demands. Availability of resources, time, and professional expertise shapes the enactment of their agency. Teachers, as street-level bureaucrats, navigate systemic shortcomings, limited infrastructure, and curricula that overestimate the realities of implementation, revealing the contested nature of educational reform.

DISCUSSION

Our discussion addresses the three research questions by interpreting findings through Lipsky's theory of street-level bureaucracy, which views teachers as public service workers who implement policy in real-world contexts shaped by resource constraints, ambiguous goals, and shifting institutional priorities. In such settings, teachers exercise discretionary judgment, developing coping mechanisms to balance policy expectations with the realities of their classrooms.

Science teachers across diverse settings offered detailed perspectives on both the constraints and successes they encountered while engaging students in the Technological World component of the Québec Education Program (QEP). We interpret these accounts to highlight systemic issues, identify creative instructional responses, and explore implications for policy, infrastructure, and teacher learning. Key themes include constraints and successes, time spent teaching the technology, support systems, availability, and quality of PLD initiatives, and teachers' conceptualization of technological thinking.

Constraints

A key issue was the distribution of tech-heavy facilities and tools. Although some schools were well-equipped, with 3D printers, drill presses, and band saws, others lacked these tools. Even in better-resourced schools, outdated equipment, large class sizes, and lack of storage created barriers to hands-on projects. Moreover, the 2007-2008 initial investment in tech-heavy infrastructure and equipment is now dated.

More critically, access to tech-heavy spaces is constrained by limited availability and staffing. One technology lab per school, serving hundreds or thousands of students, restricts project-based learning opportunities. Safety regulations require lab technician supervision. However, the lack of staffing and infrastructure, as well as problems such as poor ventilation, have led to some permanent lab closures.

These limitations compel teachers to make discretionary decisions about how and whether to implement certain aspects of the mandated curriculum. From an SLB perspective, these choices serve as coping strategies: teachers scale back projects, repurpose materials, or modify timelines in response to what is feasible in their setting.

Successes

Despite these challenges, teachers displayed creativity and resilience. Student projects, such as hydraulic labyrinths and battery testers, showcased engaging activities that aligned with the MEQ curricula. In resource-limited settings, such as Indigenous communities or adult education, teachers used low-cost tools and dollar store purchases to create equitable, localized experiences.

These acts of adaptation reflect the discretionary space of street-level bureaucrats, who must reconcile policy expectations with local realities. Teacher agency thus becomes central to educational equity, particularly when formal supports are in short supply.

Time Spent Teaching Technology

There was a wide variation in the amount of time dedicated to the Technological World. While one teacher spent a quarter of the year on it, others allocated a month or less, often deferring it until the end of the year. This inconsistency signals uneven curricular prioritization and a lack of integration across scientific domains.

Such variation also exemplifies teachers' discretionary power. Their decisions about what to teach and how to engage students are shaped by access to resources and personal expertise, rather than institutionalized support structures.

Support Systems and Professional Development

Science consultants played a crucial role in supporting teachers, providing training, creating resources, and offering personalized pedagogical assistance. However, their efforts were sometimes constrained by low interest in PLD and minimal access to release time. Our findings point to a misalignment between teacher demand for contextualized, hands-on technology training and PLD offerings. Teachers consistently reported gaps in their initial preparation to teach technology, particularly design and engineering skills.

Where formal PLD was lacking, teachers turned to YouTube, peer support, and personal trial and error. These self-directed efforts are consistent with SLBs: when policy implementation lacks support, practitioners readily develop informal solutions.

Understanding Technological Thinking

A striking finding was the conceptual uncertainty around “technological thinking.” Many teachers conflated it with the scientific method or digital literacy, suggesting a lack of clarity in training and curricula. This confusion has significant pedagogical implications. Without a clear understanding of how technological thinking differs from scientific reasoning, teachers risk reducing engineering design processes to rigid, step-by-step activities that resemble lab reports, thereby missing the iterative nature of design.

When curriculum goals are vague, teachers must invent them to align with their practice. From an SLB perspective, this discretionary space places the burden of interpretation on the teacher.

To nurture authentic technological engagement, we argue that future iterations of the science and technology curriculum in Québec must explicitly articulate the nature of design thinking and technological reasoning. Courses and PD initiatives should help teachers distinguish between inquiry-based scientific exploration and iterative engineering design. Doing so would allow teachers to frame technology education not merely as content delivery but as a way of thinking and problem-solving.

CONCLUSION

Several limitations should be acknowledged. While the sample included educators from Francophone and Anglophone sectors, as well as urban, suburban, and rural settings, it may not fully capture the breadth of experiences across all school types or regions. The findings are not intended to be generalizable but rather to capture patterns and tensions that warrant deeper investigation. Future research should expand to include a greater range and number of participants, including those from underrepresented regions, adult education, and Indigenous communities, to explore how educators implement technology and engineering practices. Longitudinal studies examining changes in practice over time could offer deeper insight into how school cultures evolve or resist evolving when integrating technology and engineering practices.

This study highlights the ingenuity that Québec science teachers demonstrate when teaching the Technological World component of the science curricula. Teachers frequently described feeling ill-prepared and inadequately supported. Many pointed to limited financial resources needed for larger-scale projects, such as 3D printing, purchasing lumber, software and laptops that integrate digital tools with engineering design. Additionally, they reported on the lack of readily available activities to guide their instruction.

While material and human resource shortages hamper their work, teachers' creativity and commitment remain powerful drivers of success. To build on this foundation, systemic investments in infrastructure, support staff, and context responsive PLD are essential. Equally important is clarifying the conceptual underpinnings of technological thinking to help teachers translate these skills in ways that allow students to experience technology as an integrated and essential part of their science education.

This research contributes to the literature on science and technology education by framing teachers as implementers of curriculum and as *street-level bureaucrats* (Lipsky, 2010) whose choices shape how curricula policies are enacted. In navigating uneven resources and local constraints, teachers make daily decisions that define how students experience the Technological World. Recognizing this role invites policymakers, curriculum developers, and school leaders to support teachers to exercise their professional judgment equitably and effectively.

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Effect of implementing a technological design approach on students' interest in science and technology classes in the 3rd cycle of primary school and the 1st cycle of secondary school

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Abstract

The global shortage of science and technology (S&T) specialists, combined with the underrepresentation of girls in STEM (science, technology, engineering, and mathematics) fields in Quebec, Canada, and internationally, raises major concerns (Roy et al., 2014; Franz-Odendaal et al., 2016; Patchen et al., 2017). These findings, combined with the importance of basic S&T knowledge and skills for all citizens, have prompted researchers to identify factors that may promote interest in S&T among both girls and boys (Christidou, 2011; DeCoito, 2016; Krapp and Prenzel, 2011; Potvin and Hasni, 2014). Among the avenues emerging from research, design-based educational activities, such as the technological design process (TDP), stand out as potential levers to stimulate interest (Rohaan et al., 2009; Weber, 2012). With this in mind, this research focuses on the impact of TDP on students' interest at the end of primary school and the beginning of secondary school, a critical period in when interest in S&T tends to decrease more sharply (Potvin and Hasni, 2018). The objective of this study is to measure the influence of TDP on short-term (situational) and long-term (individual) interest (Hidi and Renninger, 2006), while examining the differences in impact between girls and boys. A quasi-experimental design was used with 314 students and 11 volunteer teachers, who had received in-service training. Data were collected using pre- and post-test questionnaires measuring situational and individual interest, comparing activities with and without TDP. The results indicate that TDP had a positive effect on the interest of primary school students, especially for girls. However, this effect was not observed among secondary school students. The study therefore recommends early integration of TDP into the school curriculum, to stimulate interest in S&T, especially for girls.

Key Words: technological design process, interest, primary, secondary, gender

1. INTRODUCTION

Science and technology (S&T) are fundamental to modern life, driving innovations and contributing significantly to health and environmental quality. A basic scientific and technological culture is essential for all citizens (Kelley & Kellam, 2009), and the expertise of scientists and engineers is crucial for economic growth and societal well-being (Beckstead & Brown, 2006; Kerger et al., 2011).

Despite this critical importance, global enrollment in S&T training is declining (Akcaoglu et al., 2018; DeCoito, 2016; Natural Sciences and Engineering Research Council of Canada [NSERC], 2010; OECD, 2008). This trend is particularly evident among girls in Quebec and Canada (Roy et al., 2014; Franz-Odendaal et al., 2016) and internationally (Blažev et al., 2017; White, 2015). Girls remain significantly underrepresented in many STEM fields, especially technology and engineering (Belletête et al., 2020; Patchen et al., 2017).

This decline is often linked to *interest*, a key attitudinal construct (Christidou, 2011). Interest in S&T sharply decreases during the transition from primary to secondary school for many students, a trend more pronounced among girls (Holmegaard et al., 2014; Potvin & Hasni, 2018). While schools have a role, they struggle to cultivate this interest effectively.

However, research shows that specific teaching strategies can significantly develop S&T interest, especially among girls (Krapp & Prenzel, 2011; Mc Ewen, 2013; Potvin & Hasni, 2014). Hands-on activities (Brotman & Moore, 2008; Owen et al., 2008), contextualized learning (Ainley & Ainley, 2011) and cooperative approaches (Baker & Leary, 1995) positively impact student engagement. Among these, artifact design emerges as a particularly promising avenue for both genders, as girls are often drawn to design activities within a social context, while boys are attracted to tool use and construction, collectively fostering greater S&T interest. These design-based activities are often structured within a pedagogical framework known as the technological design process (TDP).

2. RESEARCH QUESTIONS

Based on these findings, this study investigates how a pedagogical model, the technological design process (TDP), impacts students' S&T interest during the critical transition between primary and secondary school. This leads to the following questions:

(i) What is the effect of activities based on a TDP model on students' interest in S&T during the primary-secondary transition?
- What is its impact on the development of short-term interest (situational interest)?
- What is its impact on the development of long-term interest (individual interest)?

(ii) Does this TDP model have a different impact on girls and boys?

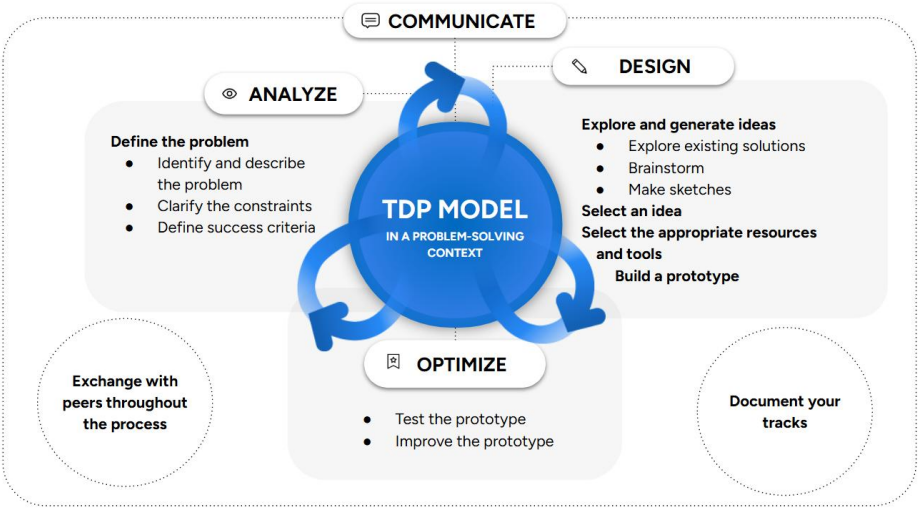
3. LITERATURE REVIEW

To provide a theoretical foundation for the problem under study, this section defines the two core concepts: the technological design process (TDP) and interest.

3.1. Technological design process (TDP)

The Technological Design Process (TDP) is a problem-solving method for designing an artifact to meet a need within specific constraints (Mathis et al., 2018). It is an iterative process where designers generate, develop, evaluate, and communicate ideas. Inspired by professional engineering, this approach is simplified for classroom use. A synthesis by Brouillette (2022) presents a model with four iterative components: analysis, design, optimization, and communication, providing a structured framework for students. This model stems from an analysis of numerous models defined under different names[1].

Figure 1.
Representation of a Technological Design Process (TDP) by Brouillette (2022)



This process begins by analyzing a problem based on a need (NRC, 2012). Students process requirements from a design brief (MELS, 2011) and consider various constraints, such as technical or economic ones (Wilson & Harris, 2004). This analysis involves identifying the

[1] Including: Technological Problem Solving (Custer et al., 2001; Mioduser, 1998), Technological Process of Design (Campbell & Jane, 2012), Project-Based Technology (Frank & Barzilai, 2006), Design-Based Learning (Doppelt et al., 2008; Kim et al., 2015), Design Process (Sung & Kelly, 2019), Engineering Design Process (Berland et al., 2014; English et al., 2012; Hynes, 2012; Shanahan et al., 2016; Wilson-Lopez et al., 2016; Zhou et al., 2017).

problem, clarifying constraints, and defining success criteria (Berland et al., 2014). This rigorous, iterative step is paramount for a successful design.

Once the problem has been analyzed, exploring and generating ideas is a key TDP component for creating multiple potential solutions (Crismond & Adams, 2012). Students brainstorm collaboratively (Turner et al., 2016), sketch concepts (Barlex, 2011) and explore existing designs (Shanahan et al., 2016). They then select the best idea that meets the project's needs and constraints (Hynes, 2012). Once a design is chosen, they plan the building process, which includes selecting the necessary tools and materials (ITEA, 2007). This process leads to the creation of a prototype, which is a simplified model representing the chosen solution path (Dym et al., 2005).

The resulting prototypes are then tested against success criteria. By observing their own and their classmates' results, students identify shortcomings (Doppelt et al., 2008). This analysis allows them to improve the prototype by revisiting earlier design stages (Berland et al., 2014).

At the end of the process, students present their solution to their peers, explaining how it meets the initial need and what they could improve (Hynes, 2012). Throughout the project, in addition to exchanging ideas with their peers, they document their work using various methods, including text, graphics, and physical prototypes (Ullman, 2010).

3.2. Interest

While the TDP provides the pedagogical framework for the intervention, the key psychological construct it is intended to influence is student interest, which is defined as a positive emotion directed toward an external subject, sparking a desire for exploration (Krapp, 2002). It is a multidimensional construct with interacting cognitive and affective dimensions that foster knowledge-building (Potvin & Hasni, 2014).

Researchers primarily distinguish between two types: situational and individual. According to Hidi & Renninger (2006), development of interest begins with situational interest—a temporary psychological state triggered by a specific activity and significantly influenced by teachers. While fleeting, this state is a crucial starting point, as repeated positive experiences can develop into the more durable form: individual interest. This developed interest is an enduring predisposition to re-engage with specific content (Deci, 1992; Hidi & Renninger, 2006; Krapp et al., 1992; Schiefele, 1991). Once established, it has a major impact on cognitive function and academic performance, as learners show greater attention and deeper knowledge acquisition (Palmer et al., 2017).

4. METHODOLOGY

This study involved grade 5 to 8 students (11 to 15 years old) from primary and secondary schools in a Quebec School Board (Canada). A total of 16 groups participated: 8 from primary school (N=121) and 8 from secondary school (N=193). The participating teachers were volunteers who received training as part of their professional development for this project.

To gather data from these participants, two data collection tools from the CRIJEST were used. The General Questionnaire (GQ) measured individual interest using validated pre- and post-tests, while the Situational Questionnaire (SQ), a modified version of a CRIJEST tool, assessed situational interest based on the most recent classroom activity. Both tools utilized Likert scales and were adapted for this research.

The administration of these tools followed two different protocols. In secondary schools, a quasi-experimental design compared experimental groups, who completed activities based on the Technology Design Process (TDP), with control groups receiving standard instruction. In primary schools, where control groups were not possible, a pre-experimental protocol was used. Each class underwent a control phase with usual teaching, followed by an experimental TDP phase. In both settings, students completed the General Questionnaire (GQ) before and after each treatment to measure their long-term individual interest. To assess short-term situational interest, the Situational Questionnaire (SQ) was administered after students completed each specific task.

To facilitate this design, four experimental activities based on the Technology Design Process (TDP) model (Brouillette, 2022) were developed, alongside four non-TDP activities for the control groups. While both sets of activities targeted identical scientific concepts, their pedagogical approaches differed significantly. The experimental TDP activities were open-ended, immersing students in an iterative cycle of analyzing a problem, designing solutions, and building and optimizing a functional prototype (such as a seismograph). In contrast, the non-TDP control activities followed a guided-exploration model where students did not create a prototype. Instead, they completed structured tasks involving the manipulation and observation of pre-existing materials—like rotating through stations of simple machines—to answer specific questions about their function. All eight activities were presented to teachers in a preparatory training session to ensure these distinct approaches were implemented as intended.

5. RESULTS

This section presents the findings from the Situational Questionnaire (SQ) and the General Questionnaire (GQ). The results are organized to address our research questions regarding the impact of the Technological Design Process (TDP) model on students' short-term (situational) and long-term (individual) interest in S&T.

5.1. Situational Questionnaire (SQ) Results

To answer our first research question about short-term interest, we analyzed situational interest during the tasks. The results are presented separately for primary and secondary schools to examine the TDP's effect across the transition period.

5.1.1. Situational Questionnaire (SQ) Results for Primary Schools

At the primary level, we investigated whether TDP-based activities generated higher situational interest than control activities. Paired t-tests were used to compare individual students' interest levels between the two treatments. The results, broken down by gender, are presented in Table 1.

Table 1.
Paired T-Test Results for Differences in Situational Interest in Primary School by Gender

Gender	Treatment	*M*	*SD*	Standard Error	*t*	*p*	*d*	*n*
Boys	Control	4.34	1.035	0.132	-2.880	0.005**	0.36	62
	Experimental	4.71						
Girls	Control	4.12	1.77	0.157	-3.457	0.001**	0.45	56
	Experimental	4.66						

*$p < 0.05$, **$p < 0.005$

The experimental treatment resulted in a statistically significant increase in situational interest for both boys (p=0.005) and girls (p=0.001). For boys, the average score rose from 4.34 to 4.71. For girls, the increase was even more pronounced, with scores rising from 4.12 to 4.66. These findings suggest that the TDP model was more immediately engaging for both genders in primary school. However, the effect size (d) was small (Sawilowsky, 2009). When data were aggregated across all 118 primary participants, this conclusion was reinforced (Table 2).

Table 2.
Paired T-Test Results for Differences in Situational Interest in Primary School

Treatment	*M*	*SD*	Standard Error	*t*	*p*	*d*	*n*
Control	4.23	1.103	0.102	-4.50	*< 0.001***	0.41	118
Experimental	4.69						

**p < 0.05, **p < 0.005*

The experimental treatment led to a statistically significant increase in situational interest compared to the control treatment (p<0.001), with the mean score rising from 4.23 to 4.69. This confirms that, for the primary school cohort, the TDP activities were more engaging in the moment, although the effect size (d) remains small (Sawilowsky, 2009).

5.1.2. Situational Questionnaire (SQ) Results for Secondary Schools

In contrast to the primary school findings, the TDP model did not have a significant effect on the situational interest of secondary students as shown in Table 3.

Table 3.
Independent Samples t-test Results for Differences in Situational Interest in Secondary School by Gender

Gender	Treatment	*M*	*SD*	Standard Error	*t*	*p*	*d*	*n*
Boys	Control	4.28	0.658	0.122	0.58	0.537	0.18	29
	Experimental	4.40	0.991	0.153				42
Girls	Control	4.35	0.752	0.122	-0.70	0.484	-0.19	38
	Experimental	4.20	0.983	0.166				35

A slight, non-significant difference appeared for boys, with the experimental group scoring marginally higher (M=4.40) than the control group (M=4.28). For girls, the opposite trend was

observed, with the experimental group scoring slightly lower (M=4.20) than the control group (M=4.35); this difference was also not statistically significant.

These results show that for both genders, the differences in situational interest are not statistically significant. This suggests that, unlike in primary school, the TDP activities were not perceived as more engaging than the standard curriculum by secondary students. This conclusion is supported by the aggregated data for all secondary participants (Table 4), which also revealed no significant difference between treatments.

Table 4.
Independent Samples t-test Results for Differences in Situational Interest in Secondary School

Treatment	*M*	*SD*	Standard Error	*t*	*p*	*d*	*n*
Control	4.32	0.708	0.087	-0.00	0.998	-0.00	67
Experimental	4.32						80

5.2. General Questionnaire (GQ) Results

Moving from immediate engagement to lasting disposition, we next analyzed the TDP's impact on students' long-term (individual) interest. This analysis directly addresses our second research question on whether the TDP model can help sustain S&T interest over time.

5.2.1. General Questionnaire (GQ) Results for Primary Schools

For primary students, we aimed to see if the TDP model could better preserve individual interest compared to the control treatment. The General Questionnaire (GQ) was administered before and after each treatment, and paired t-tests were used to compare the change in interest (gains).

Table 5.
Paired t-test Results in Individual Interest Gains in Primary School

Treatment	*M*	*SD*	*Standard Error*	*t*	*p*	*d*	*n*
Control	-0.44	1.158	0.121	-2.05	0.043*	0.35	91
Experimental	-0.03	1.178	0.124				91

*p < 0.05

The results showed a more favorable change during the experimental treatment (M=−0.03) compared to the control treatment (M=−0.44), a difference that was statistically significant. This suggests that while interest tended to decline overall, the TDP model had a protective effect, nearly maintaining students' initial interest levels. The effect size (d), however, was small (Sawilowsky, 2009).

To answer our sub-question about gender differences, this analysis was broken down for boys and girls (Table 6).

Table 6.
Paired t-test Results in Individual Interest Gains in Primary School by Gender

Gender	*Treatment*	*M*	*SD*	Standard Error	*t*	*p*	*d*	*n*
Girls	Control	-0.54	0.895	0.138	-2.646	0.011*	0.68	42
	Experimental	0.07	1.031	0.159				42
Boys	Control	-0.35	1.346	0.192	-0.756	0.454	0.18	49
	Experimental	-0.11	1.296	0.185				49

*p < 0.05

A key finding related to our second research question on gender differences was that the TDP model's protective effect on individual interest was most significant for girls, reversing what would have been a substantial decline in their interest. Specifically, while boys' interest was nearly maintained (M=−0.11), girls' scores transformed from a sharp decrease during the control phase (M=−0.54) to a slight increase during the experimental phase (M=0.07). This positive gain for girls is statistically significant and represents a medium effect size (d) (Sawilowsky, 2009), highlighting the model's unique effectiveness for this group.

5.2.2. General Questionnaire (GQ) Results for Secondary Schools

At the secondary level, the analysis tested whether the TDP model could mitigate the widely observed decline in individual interest in S&T. Independent samples t-tests compared the pre-post change in interest between the experimental and control groups.

Table 7.
Independent Samples t-test Results in Individual Interest Gains in Secondary Schools

Treatment	*M*	*SD*	Standard Error	*t*	*p*	*d*	*n*
Control	-0.36	1.536	0.186	-0.166	0.868	0.02	68
Experimental	-0.32	0.940	0.110				73

The results indicate a decline in individual interest for both the control group (M=−0.36) and the experimental group (M=−0.32). Although the decrease was slightly smaller for the TDP group, this difference was not statistically significant. This finding suggests that the TDP intervention, as implemented, was insufficient to counteract the general decline in long-term S&T interest among secondary students.

A final analysis by gender (Table 8) explored if this overall result masked different effects for boys and girls.

Table 8.
Independent Samples t-test Results in Individual Interest Gains in Secondary Schools by Gender

Gender	Treatment	*M*	*SD*	*Standard Error*	*t*	*p*	*d*	*n*
Girls	Control	-0.21	1.870	0.312	0.189	0.851	0.04	36
	Experimental	-0.27	0.956	0.184				27
Boys	Control	-0.53	1.045	0.185	-0.768	0.446	0.17	32
	Experimental	-0.35	0.939	0.139				46

Although not statistically significant, the results showed opposite trends. For girls, the experimental treatment was associated with a slightly larger decline in interest, while for boys, it was associated with a smaller decline. However, with very small effect sizes and no statistical significance, these divergent trends do not support a firm conclusion. The TDP model did not demonstrate a clear impact on the long-term interest of either boys or girls at the secondary level.

6. DISCUSSION

This discussion interprets the study's findings to answer the research questions regarding the TDP model's impact on student interest. It begins with a summary of the key results for primary and secondary school, followed by an analysis of the study's limitations.

6.1. Summary of Results

6.1.1. Results for Primary School

Answering our research question on short-term interest, an analysis of the Situational Questionnaire (SQ) using a paired t-test revealed a significant increase in situational interest among primary school students. The results showed a significant difference ($p<0.001$) between the mean score for the control treatment ($M = 4.23$) and the experimental treatment ($M = 4.69$). As situational interest is influenced by teacher-selected tasks (Gaston & Havard, 2019; Renninger & Bachrach, 2015), this increase can likely be attributed to the pedagogical strategies of the TDP model.

Addressing the question of gender differences, a gender-based analysis further confirmed that this positive effect was significant for both groups. Boys' scores increased significantly, with the mean rising from 4.34 to 4.71. Girls' scores also rose significantly, from 4.12 to 4.66. Notably, the increase in interest was more pronounced for girls (a gain of 0.54) than for boys (a gain of 0.37), suggesting that while the TDP model benefited both genders, it was particularly effective at stimulating girls' situational interest.

This strong generation of situational interest is critical, as theory posits that such repeated positive experiences can build individual interest (Hidi & Harackiewicz, 2000; Palmer et al., 2017). This leads to our second question on long-term interest, where the findings were equally compelling when considered alongside research showing that S&T interest typically declines over time (Holmegaard et al., 2014). The TDP model effectively halted the sharp decline in interest seen in the control group ($M = -0.44$), leaving the experimental group’s interest level virtually unchanged ($M = -0.03$).

Confirming this theoretical link, the analysis of gender-specific impacts on long-term interest revealed even more striking results. For boys, the model considerably reduced the decline in interest from -0.35 to -0.11. For girls, the model achieved a remarkable reversal, transforming a sharp decline ($M = -0.54$) into a significant positive increase ($M = 0.07$). This outcome is especially important as it runs contrary to the general trend in the literature where girls often show less interest in S&T than boys.

We hypothesize that these results, especially for girls, can be attributed to several key pedagogical elements of the experimental treatment, which were selected based on the scientific literature. For example, tasks were presented as concrete, meaningful problems linked to students' daily lives, an approach known to generate more interest among girls (Lawson & Dorst, 2009). A significant portion of the activities was also dedicated to design and creation, elements that appeal to creativity and are often more interesting to girls (Rohaan et al., 2009; Weber, 2012). Finally, the model strongly encouraged teamwork and mutual support, a learning environment often preferred by girls (Baker & Leary, 1995; Harwell, 2000).

In summary, the results for primary school students suggest the TDP model positively answers our research questions: it not only maintained individual interest but also reversed the trend of decline among girls by leveraging engaging pedagogical approaches.

6.1.2. Results for Secondary School

In stark contrast, when addressing our research questions at the secondary level, the TDP model did not demonstrate a significant effect on student interest. Analysis of the Situational Questionnaire (SQ) showed no detectable difference between the control and experimental treatments, with both groups having an identical mean of M = 4.32. A gender-based analysis revealed non-significant variations. For boys, the mean of the experimental group (M = 4.40) was slightly higher than that of the control group (M = 4.28). For girls, the trend was reversed, with a lower mean for the experimental group (M = 4.20) than for the control group (M = 4.35).

This lack of impact extended to long-term (individual) interest. A decrease in interest was recorded in both groups, with a slightly smaller, but non-significant, decline for the experimental group (M = -0.32) compared to the control group (M = -0.36). The gender-based analysis revealed opposing but still non-significant trends. For boys, the decline in interest was less pronounced in the experimental group (M = -0.35) than in the control group (M = -0.53). Conversely, for girls, the decline was slightly greater in the experimental group (M = -0.27) than in the control group (M = -0.21). Since none of these differences are statistically significant, we cannot conclude that the TDP model contributed to the development of interest in secondary school students.

These non-significant findings prompt an examination of potential explanatory factors. First, contextual issues could have played a role, such as a less faithful implementation of the model by specialist teachers, rigid 75-minute schedules, the "diluting" effect of other courses, and less engaging topics. Second, methodological factors must be considered. The study's reliance on a statistically less powerful independent-samples t-test, which does not control for students' initial states, is a key issue. This, combined with a smaller sample size and the possible lower receptiveness of adolescents, also provides a compelling explanation for the absence of observable effects.

6.2. Study's limitations

Despite a rigorous methodology, the results of this study on youth interest in science and technology (S&T) are not generalizable and should be interpreted with caution. To better assess the impact of the TDP model, a longitudinal design following students from primary to secondary school would be necessary. Furthermore, a larger participant sample would likely provide a

clearer picture of the experimental treatment's impact. Another key methodological limitation involves the researcher's dual role (also serving as a pedagogical advisor), which may have created a social desirability effect and contamination between the control and experimental treatments. Finally, relying exclusively on questionnaires precluded the collection of important contextual data, which could have been captured by other tools, such as a logbook, to better account for threats to the study's internal validity.

7. CONCLUSION

This research aimed to evaluate the impact of a Technological Design Process (TDP) model on student interest in science and technology (S&T) during the primary-to-secondary school transition. The results demonstrated that while the effect was not conclusive at the secondary level, the model proved to be particularly effective in primary school. It not only succeeded in halting the commonly observed decline in interest but also caused a significant increase in interest among girls, even reversing the downward trend in their individual interest. Based on these findings, this paper formulates concrete recommendations and highlights the major impacts of this study for the fields of education and research.

For the educational system, two main recommendations emerge. First, pedagogical approaches like the TDP model should be integrated early in a student's education. By doing so, educators can build a durable foundation of interest in S&T during the primary years, which can act as a protective buffer during the critical transition to secondary school—a period often marked by declining engagement. Second, the pedagogical design of the activities is crucial. Our results suggest that to maximize engagement for all students, and particularly for girls, it's wise to propose authentic problems anchored in daily life that also incorporate creative design and collaborative teamwork. To this end, an analysis of school curricula would be relevant to build bridges between technological concepts and students' fields of interest.

The impacts of this research are twofold. On a scientific level, it provides solid evidence that a targeted pedagogical strategy can not only stimulate interest in S&T but also reduce the gender gap. It highlights the effectiveness of key components such as creative design, collaboration, and contextualization, which strongly resonated with the girls in the study. On a didactic level, a significant contribution of this research is its explicit definition of the TDP process.

Finally, this study paves the way for future research. It would be valuable to more precisely identify which features of the model contribute most to student interest or to explore the best training strategies to support teachers. By offering both a proven model and avenues for improvement, we hope to have made a tangible contribution to solving a major challenge: developing a diverse future generation in science and technology by giving all students—girls and boys—the desire to create, innovate, and understand the world around them.

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Developing STEAM Education Programs for a Sustainable World

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Abstract

School education around the world has been making efforts to prepare for changes in future education and to enhance students' self-directed learning capabilities. In South Korea, convergence education has been implemented as a national education policy since 2010 with the purpose of increasing students' interest in science and technology and fostering science and technology-based problem-solving skills. In addition, Korea's new national curriculum emphasizes sustainable development under the name of 'Ecological Transformation Education'. The purpose of this study is to develop STEAM education programs for a sustainable society for middle school students. This was implemented for one year until 2025 with financial support from the Korean government. Specifically, six STEM programs based on sustainable development were developed for 8th graders. The developed programs consisted of two science-based, two technology-based, one computer science-based, and one mathematics based program, and field application study was also conducted. As a result of field study, attitudes toward engineering and STEM were improved. The revised curriculum of 2022 will be implemented from 2025 in South Korea, so the developed program will be used as integrated teaching materials in conjunction with classes at schools. In addition, classes based on the developed program should be implemented at schools to continue research on the effectiveness of the program.

Key Words : Sustainable, Middle School, Students, Effects, STEAM

1. INTRODUCTION

The Fourth Industrial Revolution (4IR), driven by artificial intelligence (AI), big data analytics, and the Internet of Things (IoT), is accelerating the transition from an industrial society to an intelligent information society. AI-based services now personalize information and decision-making and widespread IoT networks seamlessly connect the physical and virtual realms, greatly expanding data collection and utilization. As a result, organizations have shifted to a data-centric paradigm that optimizes operations and enhances social efficiency. However, the explosion of interconnected information is further increasing systemic complexity and uncertainty (Kim, 2022).

Amid this chaos, key policy frameworks emphasize the importance of learner agency and transferable competencies. The OECD's Education 2030 vision emphasizes the need for students to act autonomously, collaborate effectively, and contribute to individual and collective well-being in an unpredictable future (OECD, 2018). Complementing this, UNESCO's "Reimagining Our Futures Together" emphasizes ecological, multicultural, and interdisciplinary learning so that students can critique, create, and apply knowledge responsibly in diverse contexts (UNESCO, 2021). Therefore, education systems must foster the capacity of students to engage in self-directed and collaborative inquiry that addresses unstructured real-world problems.

Korea's 2022 revised national curriculum strengthens basic literacy in language, mathematics, and digital technology while incorporating "citizenship, individual and societal sustainability, and ecological sensitivity" across learning objectives and core competencies. In particular, the curriculum institutionalizes ecological transition education to prepare learners for climate issues and aligns national education priorities with the *Paris Agreement* (Ministry of Education, 2022a).

In this national curriculum, Korea's convergence education (STEAM) emphasizes that students can integrate science and technology knowledge with creative problem-solving skills. STEAM programs promote higher-order thinking, foster a sustainable development mind-set, and position learners as active designers of the future by connecting classroom learning to real-world issues. Implementing such programs at the middle school level, particularly through flexible curriculum spaces such as semester-long grade-level modules and creative experiential activities, meets both the structural requirements of the 2022 revised curriculum and the educational demand for deeper, more personalized learning experiences (Ministry of Education, 2022a).

The main purpose of this study is to develop and implement sustainability-oriented STEAM programs in Korean middle schools. The program aims to increase students' interest in science and technology, foster convergent thinking and problem-solving skills, and provide a scalable model that teachers can easily adopt within a new curriculum framework. This will address the urgent educational challenges posed by the Fourth Industrial Revolution and achieve the broader goal of preparing youth for success and leadership in an increasingly complex, data-rich, and interconnected world.

2. LITERATURE REVIEW

2.1. 2022 Revised National Curriculum in South Korea

The 2022 Revised National Curriculum systematically organizes the competencies to respond to the volatility, uncertainty, and complexity that are the characteristics of future society based on educational values and the direction that education should pursue. The curriculum presents six core competencies: self-management competencies, knowledge and information processing competencies, creative thinking competencies, aesthetic sensibility competencies, cooperative communication competencies, and community competencies (Ministry of Education, 2022a).

2022 National Curriculum is designed to enable students to apply and utilize the knowledge and skills of language, mathematics, and digital literacy when learning subjects and dealing with real-life problems throughout elementary and secondary education. Digital literacy is presented as a basic competency, focusing on developing the ability of students to critically read and creatively process information in finding, interpreting, and evaluating data.

In addition, the “school autonomous time” was introduced to allow schools to have autonomy in curriculum operation, reflecting opinions from the field on the need to develop a curriculum that takes into account regional and school characteristics. Schools can use this autonomous time to open new subjects or activities according to the school level and context. Moreover, career-linked education was introduced along the continuum of student growth that connects the curriculum contents between school level, career planning, learning methods, and life adaptation. This career-linked education has two important meanings: 'curriculum linkage and learning adaptation during school level transition' and 'cultivating learners' career awareness and career setting ability'. It systematically operates various career exploration activities to support learning according to each student's learning level and learning method.

Finally, the 2022 National Curriculum focuses on cultivating students' ability to actively respond to the uncertainties of the future society caused by digital transformation, climate, and ecological environment changes. Community competencies is emphasized as the ability to actively and responsibly participate in the development of a sustainable human community based on the open and inclusive values and attitudes required of members of local, national, and global communities. This innovation is significantly different from the existing curriculum, and the 2022 revised curriculum provides a comprehensive framework that prepares students to grow into 'self-directed individuals with inclusiveness and creativity' who can succeed in an uncertain future (Ministry of Education, 2022b).

2.2. Emphasis on Convergence Education for Future Education Practice

The Korean government has been consistently suggesting the direction of future education in response to social changes. Gyeonggi Future Education 2030 emphasizes that students should experience diverse activities and live independently in their lives, and emphasizes a paradigm shift that boldly breaks away from the uniform framework of existing segmented subject-

centered curricula, standardized timetables, class-based learning, and textbooks (Gyeonggi Provincial Office of Education, 2021). Seoul Future Education 2030 emphasizes competency-based education for the transition to future education. It emphasizes teaching and learning methods and evaluation that integrate and explore diverse knowledge related to one specific problem or phenomenon, one topic beyond subject-specific knowledge, identity (Seoul Metropolitan Office of Education, 2022). Various policy studies on future education also emphasize project-based collaborative learning, integration of curriculum and life, education for fostering higher-level thinking skills, convergence education between subjects (STEAM), and online and offline convergence education (Hong et al., 2016; Hwang et al., 2019; Joo et al., 2016; Kim et al., 2016).

In order to strengthen convergence education by subject, we support the design of learning processes so that students can discover various real-world problems within the curriculum by subject and explore them in connection with subject knowledge. We expand learning spaces online and suggest teaching and learning methods using various online sites and platforms to support diverse learning that connects inside and outside of school. We are striving to realize customized education through intelligent learning platforms and share and distribute educational content and SW that incorporate cutting-edge technologies such as AI, big data, and AR/VR/XR.

According to the findings of a survey of 871 in-service teachers nationwide on the past 10 years of convergence education (STEAM) in Korea, 449 (51.5%) in-service teachers were found to be practicing convergence education, and the reasons for this were voluntary efforts by teachers and educational necessity for preparing for the future society (Kwon et al., 2021).

2.3. Sustainable Development Goals

The SDGs (Sustainable Development Goals) are common goals for humanity that the world must achieve together by 2030, adopted by the UN in 2015. As environmental pollution such as resource depletion and abnormal climate become more serious, the meaning of sustainability, which means “meeting the needs of the present generation with the needs of future generations without limiting the possibilities of future generations,” is emphasized. In detail, it consists of 17 goals and 169 sub-goals, no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industrial innovation and infrastructure, reduced inequality, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace, justice and strong institutions, and partnership for the goals(UN, 2015).

In the field of education, programs are being developed and researched to help future generations of students understand the importance of sustainable development and develop the ability to practice it. In particular, the Ministry of Education and Korea Foundation for the Advancement of Science and Creativity in Korea developed school-level programs linked to all areas of the SDGs from 2017 to 2020 and distributed to 17 middle schools.

2.4. Global Trends in Convergence Education

Efforts to expand learner-directed, convergence education (STEM/STEAM) are taking place internationally. The National Inventors Hall of Fame in the United States brings together experts from diverse fields such as biology, urban studies, psychology, and history to design and run high-quality STEM programs. It also operates makerspaces that provide information, workspaces, and fabrication tools for engineering design and project-based learning for learners at all levels.

Canada's "Canada 2067" roadmap mandates completion of interdisciplinary courses prior to high school graduation, promoting self-directed inquiry and cross-curricular collaboration through structured project activities.

The United Kingdom includes interdisciplinary programs in its regular curriculum and has implemented a universal STEM access policy to address gender and socioeconomic disparities, ensuring equal opportunities for self-directed projects (Kwon et al., 2021).

Successful implementation of interdisciplinary learning (STEAM) at the school level depends on a clear vision, integrated curriculum framework, and strong community partnerships.

Exemplary schools articulate their future vision and core values, design learning environments that integrate curriculum with extracurricular and interdisciplinary projects, and build partnerships with local industry, universities, and parent communities. These schools invest in both physical makerspaces and digital platforms to support engineering design, create environments that sustain educators' STEAM expertise through professional learning communities, and introduce career exploration and character education programs that align with new career and civic competencies (Park et al., 2023).

The recent rapid development of digital technologies and the Fourth Industrial Revolution require flexible learning environments that are available anytime, anywhere, with integrated online-offline education models, and personalized learning paths to keep pace with changing learner needs and sustain the dynamics of innovative teaching and learning.

3. METHODOLOGY

3.1. Research Design

The goal of this study is to verify the effect of convergence education (STEAM) programs developed based on sustainable development for middle school students on students' attitudes toward STEAM, and the research procedure is shown in Figure 1.

Figure 1.
Research Procedure

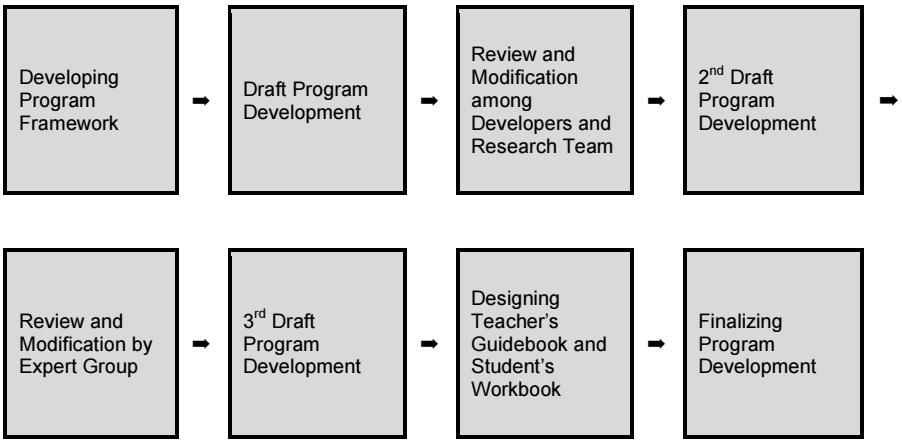
To carry out this study, a basic research framework was established by analyzing previous research of the convergence education programs. The middle school program development team, consisting of experienced and professional teachers, selected the theme of the STEAM program for sustainable development. Then, the program was completed through repeated discussions with the basic research team and consultations with external experts. The program development process is shown in Figure 2. The field application team, composed of in-service middle school teachers, tested the developed program with students in six schools to confirm the program's field suitability. The final program was modified and completed based on field applications and expert advice. Finally, the field application team analyzed the effectiveness of the program by pilot-applying the developed program to students in 6 schools.

This study developed a convergence education (STEAM) program for sustainable development through an analysis of the 2022 revised curriculum, global trends, promising job analyses, and previous research on STEAM & STEM program development.

Through a comparative analysis of Korea's 2022 revised national curriculum and the 2015 Revised National Curriculum, career elements for second-year middle school students were extracted and the curriculum was reconstructed. In addition, six convergence programs (teacher's guidebooks, student workbook, media content materials) were developed for second-year middle school students.

The results of the topic selection of the convergence education (STEAM) program were developed through research team consultation, and review and modifications were made based on external expert advice. After confirming the suitability of the six programs through field application, the final program was modified and completed based on expert advice and implications from pilot application.

Figure 2.
Program Development Procedure



3.2. Participants

This study used a pre- and post-test design to evaluation the program's application, targeting a single group of 450 students from six middle schools as shown in Table 1.

Table 1.
Field Studies: Implementation in Schools

Program	Hour	School	Application period	Class Subjects	Number of students
Medical exploration life for our healthy body	5	E Middle School	2024.10.22. ~10.31.	Science	50
Stop the global temperature rise!	5	D Middle School	2024.11.1. ~11.13.	Science	30
Sustainable AI Smart City	6	C Middle School	2024.10.5. ~11.18.	Technology &Home-economics	270
A world convenient for everyone	5	B Middle School	2024.10.8. ~11.15.	Technology &Home-economics	40
Catch the digital citizenship!	5	A Middle School	2024.10.21. ~11.8.	Technology &Home-economics	30
Zootopia fostered by big data!	5	F Middle School	2024.10.14. ~10.28.	Mathematics, Science	30
Total Participants					450

3.3. Data Collection and Analysis

The developed convergence education (STEAM) program was applied to 450 students from 6 schools, and a survey using a test tool was conducted on 311 students who agreed to participate in the survey.

In this study, we analyzed the data of 311 students who participated in the pre-test and post-test of the attitude toward engineering, STEAM attitude, and digital literacy measurement tools. The Engineering attitude test (Lee, 2008) was modified and used as the “Development of Attitude Scale toward Technology”, The STEAM attitude test was used as the STEAM attitude test tool developed by Park et al. (2019). The digital literacy test tool was used as the 'digital literacy' test tool developed by Kim et al. (2023).

Prior to the survey, the purpose of the survey was sufficiently explained to the students, and consent was obtained in advance to conduct an online survey for students who wished to participate. The survey was conducted before the program started, and the post-survey was conducted within a week after the program ended.

4. RESULTS

4.1. Program Development

In the 2022 National Curriculum, six types of STEAM (convergence) education programs (teacher guidebook, student workbook, teacher’s media and content materials) for second-year middle school students were developed. The developed programs are shown in Table 2.

Table 2.
Title and Concentrated Area for Final Programs

Program Title	Concentrated Area	Class time
Medical exploration life for our healthy body	Science	5
Stop the global temperature rise!	Science	5
Sustainable AI Smart City	Technology	6
A world convenient for everyone	Technology	5
Catch the digital citizenship!	Information	5
Zootopia fostered by big data!	Mathematics	5

As shown in Figure 3 and Figure 4, six convergence (STEAM) education programs for sustainable development have developed student workbooks for systematic learning by students. In addition, six teachers' guides were developed to help teachers understand and guide the programs.

Figure 3.
The Contents of Teacher's Guidebooks

Order	Table of Contents	Contents
1	Annual Guidance Plan	An annual instructional schedule specifying achievement criteria and allotted instructional hours.
2	Overview of the Convergence Education (STEAM) Program	Provides materials that support the understanding of educational objectives, related subject areas, curriculum integration, and a summary of content activities organized by instructional periods.
3	Theoretical background	Offers in-depth explanations of key theories relevant to the program.
4	Teaching-Learning Plan by Class	Presents teacher activity guidelines through period-specific teaching and learning plans
5	Points to note on the map	Includes supplementary materials to enhance the quality of instruction
6	Teaching Resources for Teachers	Provides classroom reference materials and career-related resources associated with the program
7	Career introduction and self-reflection	Introduces promising career paths related to the program content

Figure 4.
The Contents of Student Workbooks

Order	Table of Contents	Contents
1	Prologue	Overview of learning and experience through the program
2	Definition of situation-related problems through pictures	Invitation to problems by presenting problems related to the students' lives as members of future society, activities to accept them as problems in their lives to explore students' career paths.
3	If you learn this class unit	Presentation of class objectives for each period.
4	Learn more	Increasing class motivation and expanding classes to problem situations in daily life.
5	Process -> Reflection	Linking class process and self-reflection through learning-driven activities
6	Mini activities	Increasing class interest and applying theory to daily life through mini activities such as word quizzes and true/false quizzes.
7	Learning words	Unraveling word meanings through fostering language skills necessary for class.
8	Here's a quick note	Providing important or thought-provoking content and class tips to increase learning comprehension

4.3. Effects of Korean STEM Education Programs: Students' Attitude

A survey was conducted on six schools that applied the STEAM program to analyze the effectiveness of each program. The status of participating schools by test is shown in Table 3.

Table 3.
The Status of Participating Schools by Effectiveness Study

School	Attitude toward Engineering	STEAM Attitude	Digital Literacy
A Middle school	22		22
B Middle school	36		36
C Middle school	165		165
D Middle school		23	23
E Middle school		27	27
F Middle school		38	38
Total Participants	223	88	311

As shown in Table 4, 223 students participated in the attitude test toward engineering. The pre-test average score was 2.59 points, the standard deviation was 0.313, and the post-test average score was 2.72 points, the standard deviation was 0.40. The post-test score improved by 0.14 points compared to the pre-test, and there was a significant difference between the pre-test and post-test scores.

Table 4.
Survey Results related to STEAM Effectiveness

Item (N)	Pre-Survey		Post Survey		t	p
	Mean	Standard Deviation	Mean	Standard Deviation		
Attitude toward Engineering (223)	2.5874	.31278	2.7239	.40061	-5.326	.000
STEAM Attitude (88)	3.0025	.46085	3.2844	.51724	-5.440	.000
Digital Literacy (311)	2.9418	.46904	3.1579	.48261	-8.159	.000

As a result of conducting the STAEM attitude test on 88 students, the pre-test average score was 3.00 points, the standard deviation was 0.461, and the post-test average score was 3.28 points, the standard deviation was 0.517, an improvement of 0.28 points. The post-test average score improved compared to the pre-test average score in all sub-items.

As a result of the digital literacy test, the pre-test average score of 311 students was 2.94 points, the standard deviation was .469 points, and the post-test average score was 3.16 points, the standard deviation was .483 points, which is an improvement of 0.22 points. In all sub-items, the post-test average score improved from the pre-test average score.

5. CONCLUSION AND DISCUSSION

STEAM education programs developed through this study were able to confirm significant educational effects in the areas of attitude toward engineering, STEAM attitude, and digital literacy tests.

The developed STEAM program set is designed to integrate at least two subjects among science, technology, mathematics, information, career guidance, and the arts—within the 2022 revised middle-school national curriculum to solve real-world problems, making it readily implementable in middle-school settings. It can be flexibly applied not only to Grade 8 regular classes but also to creative project activities and club projects, broadening students' learning experiences. Diverse professional development sessions (e.g., a workshop, in-service teachers' training etc.) will strengthen teachers' ability to design convergence lessons and the developed programs can be delivered effectively during flexible scheduling periods or autonomous activity times. Through integrating science, mathematics, technology, engineering, and the arts, the program supports exploration of diverse career paths suited to the digital-transformation era while simultaneously developing students' scientific and technological literacies.

It also establishes a foundation for performance-based assessment models, enabling objective measurement of student achievement, and provides detailed teaching and learning guidance to enhance classroom applicability. Ongoing research and wider field implementation are expected to validate the program's effectiveness and promote its educational adoption.

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Integrating Microelectronics into Technology Education: *Exploring the Influence of Workforce Demands*

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Abstract

Global investments in semiconductor advancement and microelectronics manufacturing have heightened the demand for a skilled STEM workforce in this critical industry. As a result, there is a growing demand to align educational curricula with these industry needs. Therefore, this paper explores how technology education in secondary schools can integrate semiconductor and microelectronics content, reviewing curricular and technological adaptations required, while also looking at the broader philosophical and ethical considerations of aligning national workforce initiatives with classroom practices. Drawing on a preliminary case study of educators developing microelectronics-focused instructional units, the paper explores the opportunities and "lessons learned" from embedding specialized technology content into secondary curriculum. Preliminary results suggest that technology education's inherently flexible, hands-on approach can accommodate emerging STEM workforce needs, motivating student interest through real-world design and problem-solving activities. At the same time, the push to meet immediate workforce demands can raise questions about maintaining the subject's broader educational aims. Educators will likely need to reconcile their curriculum's design-based culture with industry needs that may prioritize technical competencies or career foci. Therefore, the fast-paced and continuous evolution of technology curriculum can emphasize the importance of reflective practice in teaching and curriculum development.

Key Words: Technology Education, Microelectronics, STEM Workforce Development

1. INTRODUCTION

Today, most of our daily activities are carried out through electronic devices. During the COVID-19 pandemic, a global disruption of the supply chain of microchips (i.e., semiconductor products) impacted the normal operation of the electronics industry (Luther, 2021). In contemporary society, most data are processed electronically and are closely related to personal privacy and national security. In response, the U.S. as well as several other countries enacted legislation to foster domestic semiconductor industries and stabilize their microelectronics supply chains (McKinsey & Company, 2022). Based on this legislation (e.g., the U.S. CHIPS and Science Act of 2022), national-level initiatives have been implemented to cultivate talent in the semiconductor field (Deliott, 2022; Deliott & the Semiconductor Alliance, 2023; Deliotte, 2024; The White House, 2024). In response, a K-12 microelectronics workforce development project was launched in 2023

to help teachers develop, implement, refine, and share educational materials that enable K-12 students to understand and experience the principles of the semiconductor industry. An emphasis of these materials is to explore the method by which semiconductors, as raw materials, are processed and used to manufacture microelectronic devices (also known as microchips). As part of these efforts, secondary technology education classrooms emerged as a strategic pathway to introduce students to relevant skills and concepts from an early age (Hacker, 2023; Strimel, 2025). Therefore, this paper examines how technology education in secondary schools can integrate semiconductor and microelectronics content, exploring the curricular and technological adaptations required along with philosophical considerations of aligning national workforce initiatives with classroom practice.

The purpose of this preliminary case study was to explore a microelectronics workforce development initiative for K-12 teachers/students and review the potential influence of emerging workforce demands on secondary technology classrooms. Specifically, the authors sought to answer the following questions:

- How do secondary technology educators adapt curriculum to embed microelectronics concepts?
- What successes and opportunities surface during microelectronics integration?
- How do secondary teaching teachers reconcile workforce imperatives with broader educational goals?

The preliminary results from this case study reveal practical insights for integrating microelectronics content into secondary school classrooms as well as considerations for technology educator responses to workforce trends.

2. Methodology

This preliminary study employed an exploratory case study approach to review how microelectronics instructional content—developed in response to emerging industry needs—was adapted and implemented in school settings. A case study was considered appropriate, as it allowed for an in-depth exploration of teachers' experiences and the meanings they constructed through the actual process of classroom implementation (Yin, 2018). As part of the K-12 microelectronics workforce development project, 16 secondary school technology teachers received training to develop and implement microelectronics-focused units of instruction (approximately 500 minutes of instruction per unit). Each of these teachers adapted the co-developed instructional unit to fit the specific contexts/needs of their schools and then implemented it in their classrooms. After developing the initial instructional unit and obtaining the necessary student and parent consent and assent, the researchers observed each day of classroom implementation by each teacher. During these observations, implementation notes were taken by the researchers to document the flow of instruction and to capture the reactions of both students and teachers. The developed instructional units along with the classroom observation field notes were reviewed to answer this study's research questions.

3. FINDINGS

3.1. How do secondary technology educators adapt curriculum to embed microelectronics concepts?

The technology teachers developed five instructional units related to microelectronics. In general, these units emphasized problem-solving processes through which students developed an understanding of microelectronics manufacturing. Students were engaged in hands-on activities to build electronic circuits and learned how to control electronics using programming. The following sections provide an overview of the instructional units.

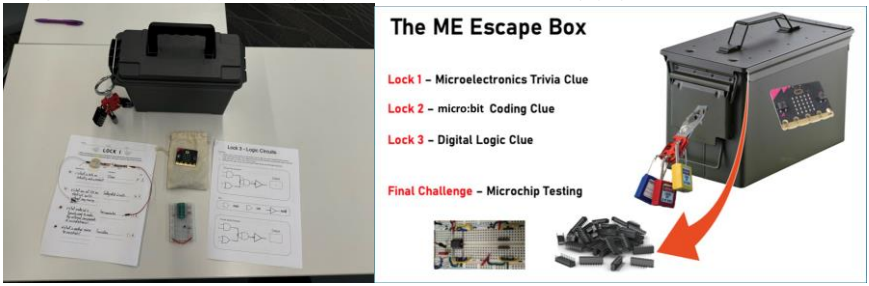
3.1.1. Unit to Demystify the Inner Workings of Microchips

The learning objective of this secondary technology unit is to help students develop a fundamental understanding of microelectronics through a unit project to create an "Escape box." An escape box is a puzzle designed to mimic the experience of an escape room. The escape box involves participants solving a series of puzzles, typically within a given timeframe, to unlock the box and reveal something hidden inside. To do so, participants must unlock a series of combination locks using various clues or riddles they must decipher to reveal the combination for each lock. In this unit, students create an escape box used as a fun way to teach others about microelectronics and how microchips work. Students create various clues for their classmates to decipher and unlock three locks to open the escape box. The three clues are developed based on 1) an understanding of basic microelectronics concepts, 2) programming a microcontroller, and 3) solving digital logic circuit puzzles. Once the box is open, six unmarked microchips are revealed. To complete the escape box, the students must create a "chip tester" circuit to test the microchips and determine which microchips work properly and are not considered "counterfeit microchips." This unit consists of five lessons for middle and high school students. The instructional activities for each lesson are described in Table 1.

Table 1.
Instructional Activities for Each Lesson.

Unit Lessons	Instructional Activities
Lesson 1: The Little Black Box	Learn about microelectronics and semiconductors; create an electronic quiz puzzle for the escape box.
Lesson 2: Coding with Chips	Create a microcontroller-based puzzle that uses a sensor to provide an input into a program and produces a displayed output with the lock combination for the second lock in their escape box.
Lesson 3: What's on a Chip?	Explore logic gates and create digital logic circuits.
Lesson 4: Chip Detectives	Investigate counterfeit microchips and build a "chip tester" using breadboards.
Lesson 5: The Final Countdown	Test and evaluate escape boxes; share findings and make recommendations.

Figure 1.
Escape Box and Activity Sheets (left) and Overview of the Clues (right)



3.1.2. Unit on Microelectronics Packaging

In this unit, students explore microchip packaging by designing and producing a printed circuit board (PCB) that functions as a random dice generator (see Figure 2). Microchip packaging is the process of enclosing a semiconductor chip within a casing to protect it from the external environment and facilitate electrical connections needed for it to be integrated into electronic devices. The instructional lessons include circuit design (see Figure 3), PCB milling using a CNC machine (see Figure 4), soldering of electrical components (see Figure 5), and the presentation of working prototypes to a mock microelectronics engineering company for simulated production review. The unit consists of seven lessons designed for upper secondary technology classrooms.

Figure 2.
Dice Roller Output

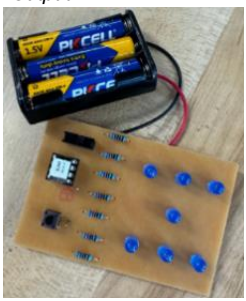


Figure 3.
Circuit Design Electronic Dice Roller PCB

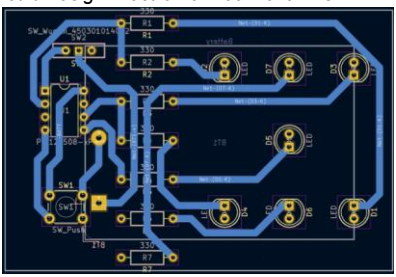
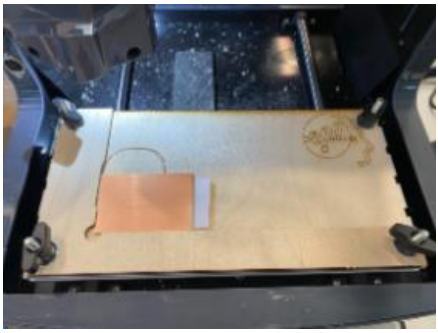
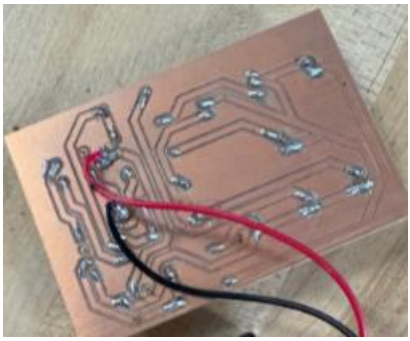


Figure 5.
PCB milling using CNC

Figure 4.
Soldering of electrical components





3.1.3. A Unit on Sensors

This unit guides students through designing and building a smart home system using sensors and a micro:bit, programmed in Python, following the engineering design process. The unit consists of eight lessons and is designed for students in lower secondary (see Table 2).

Table 2.
Instructional Activities for Each Lesson.

Unit	Instructional Activities
Lesson 1: Make Sense	Introduction to sensors and coding in the contest of smart home design
Lesson 2: What makes a computer a computer	Explore what defined a computer, Introduction to microcontrollers
Lesson 3: Functional design	Understand and create functions to apply to smart home systems
Lesson 4: Make some sense	Assemble sensors and create sensor-based functions
Lesson 5: Plan it out	Design smart home system using flowchart and pseudocode
Lesson 6: Try it out	Build a model and test Python code using micro:bit and sensors
Lesson 7: Test it out	Evaluate the system using a rubric (efficiency, usability, etc.)
Lesson 8: Design / Redesign	Modify design based on feedback and implement more complex logic

3.1.4. A Unit on Developing Electronic Products

This unit challenges students to design and develop an electronic expansion pack for a programmable robotics platform. An electronic expansion pack is a set of electronic components that can be added to the existing robotics platform to enhance its functionality or improve its performance. Students are tasked with developing a design proposal for this expansion pack, considering environmental impact, cost, appeal, and compatibility with the current robotics platform. Throughout this project, students are positioned to learn fundamental concepts of electricity, power generation, green energy, computer programming, and material sourcing. The unit consists of ten lessons designed for students in lower secondary.

3.1.5. A Unit on Reliable Microelectronics

The global chip shortage, exacerbated by the COVID-19 pandemic, caused disruption across various industries, highlighting the critical need for resilient supply chains in the semiconductor sector. In response, this unit engages students in exploring potential solutions to establish a stable and sustainable supply of semiconductor chips. Through this process, students develop an understanding of the semiconductor industry and its economic implications. Figure 6 highlights a letter from a fictitious client that introduces students to the design challenge at the center of the unit.

Figure 6.
The scenario presented to the students

3.1.6 Concepts and Technologies Across the Units

Across the five instructional units, a set of microelectronics- related concepts were commonly introduced through the student activities. These concepts are detailed in Table 3.

Table 3.
Microelectronics Concepts Introduced Across the Units.

Concepts	Description
Engineering Design Process (EDP)	All units are structured around the iterative EDP stages—define, learn, plan, try, test, decide—guiding students from problem scoping through solution recommendation.
Circuit Fundamentals & Electronics	Students build and analyze series/parallel circuits on breadboards, apply Ohm's Law, and explore LEDs, resistors, and diodes to ground some abstract theories in hands-on prototyping.

Microelectronics & PCB Design	Units introduce microchips and semiconductors, culminating in PCB milling and soldering tasks (e.g., designing an electronic dice roller) to simulate real-world microelectronics packaging.
Digital Logic & Testing	Through the escape-box puzzles, students apply logic gates (AND, OR, NOT) and build circuit testers to differentiate genuine versus counterfeit ICs.
Block Coding & Microcontroller Programming	micro:bit devices serve as entry points to coding, data collection (e.g., pedometer walks), and interactive control of circuits—bridging computing and physical systems.
Systems Thinking & Supply Chains	The units expand design thinking into economic and ethical dimensions, examining microchip supply-chain vulnerabilities and prompting evidence-based relocation proposals.
Data Representation & Algorithmic Planning	The units are positioned to help develop students' abilities to formulate flowcharts and pseudocode for sensor-based challenges, emphasizing algorithmic decomposition and decision logic.
Sustainability & Societal Impact	Environmental considerations—renewable versus non-renewable energy, green-energy—are woven throughout to foster awareness of the broader implications of design choices.

Also, across these developed units a suite of hands-on tools and technologies are used to support engaging instruction on microelectronics. These devices are detailed in Table 4.

Table 4.
Technology/Tools Introduced Across the Units to Support Microelectronics-focused Instruction.

Common Technologies & Tools	**Typical Unit Usage**
Breadboards & Jumper Wires	Rapid prototyping of circuits in early lessons (LED series/parallel builds, IC testing).
micro:bit Microcontrollers	Block-based coding, sensor integration, and interactive control of LEDs or servos.
Printed Circuit Boards (PCBs)	Milling or prefabricated PCBs for final projects, followed by soldering of components.
Soldering Irons & Multimeters	Teaching proper solder techniques and circuit diagnostics.
Robots	Energy, power, and block-coding explorations via electric expansion packs, linking physical computing with design constraints.
Engineering Design Posters	Visual scaffolds of the EDP stages that students manipulate (sliders/posters) to self-monitor progress.
Flowcharting & Pseudocode Templates	Structured worksheets and chart paper for algorithm planning.
Client Briefs & Decision Matrices	Authentic stakeholder memos and matrices to evaluate design trade-offs, emphasizing evidence-based reasoning.

Together, these concepts and tools were used to create microelectronics curriculum with a goal of bringing together electronics fundamentals, computational thinking, engineering practices, human-centered design, and socio-economic awareness—hopefully preparing K–12 learners for technical proficiency and reflective, responsible engagement with the microelectronics industry.

3.2. What successes and opportunities surface during microelectronics integration?

The review of implementation notes revealed some successes and opportunities that surfaced from these microelectronics-focused instructional units. Among the successes observed, students demonstrated engagement, as noted in comments such as "Most students seem very engaged." This can suggest that the activity successfully captured students' interest and fostered active participation. Additionally, students consistently worked together with their group members to solve problems throughout many of the activities. The activities also seemed to provide learning opportunities for complex concepts, such as distinguishing between microelectronics and electronic components, offering students the chance to engage with and apply more advanced technical skills.

Within these units, one of the consistently highlighted areas of interest was the use of client letters to frame each lesson as an authentic engineering activity. According to McDonnell et al. (2025) a client letter is a written or electronic message—real or fictional—from a "client" presenting a problem or challenge, used to frame an authentic, real-world scenario that engages students in contextualized, criteria-driven problem-solving and design work. Across all five units, students begin by reading a letter provided by a fictitious, but authentic-sounding client. The letters situate the students work/learning in a real-world context, clarify deliverables, and provide stakeholder constraints, see Table 5. Overall, embedding client letters throughout the curriculum seemed to transform abstract microelectronics concepts into meaningful, stakeholder-driven engineering tasks.

Table 5.
Details how these letters supported the instruction.

Client Letter Features	Description/Examples
Setting an authentic problem space	At the start of the escape box unit, students receive a letter from a new microelectronics packaging company explaining their community-education mission and requesting an interactive escape-room box that demystifies microchips. This initial client brief immerses students in the define stage of the EDP, compelling them to interpret industry goals before ideating solutions.
Clarifying criteria & constraints	Each subsequent lesson of the escape-box unit opens with a targeted letter that specifies technical requirements—e.g., "design a puzzle that uses a microcontroller to reveal the next lock combination" —or testing protocols for counterfeit chip detection. By embedding clear deliverables and performance criteria in every letter, students learn to align their designs with stakeholder needs and refine their projects iteratively.
Fostering stakeholder communication	In the electronic dice roller unit, learners receive a follow-up letter from a company's COO requesting documentation and demonstration circuits for community outreach. Drafting written recommendations and process logs can cultivate professional communication skills—writing concisely for an external audience, justifying design choices, and responding to real feedback.

Enhancing motivation and ownership	Framing tasks as responses to authentic letters can elevate student engagement. Rather than "completing a worksheet," learners perceive themselves as engineers contracted by an actual company. This situated motivation can help boost persistence, creativity, and the quality of final deliverables, as students engage in addressing genuine challenges and know their work "matters.
Reinforcing evidence-based reasoning	Closing each unit, students write summary letters back to the client—justifying why they made specific design decisions. These reflective letters can drive home the value of evidence and justification, tying together technical learning with audience-centered communication

The implementation field notes also reveal some potential challenges faced. Notably, students experienced some conceptual confusion, as evidenced by remarks like "not sure students are understanding the difference between criteria vs constraint" and "a bit of a confusion point: semiconductor made of sand?" These statements can highlight gaps in students' understanding of fundamental microelectronics and engineering concepts. Furthermore, some students exhibited frustration with the difficulty of the challenge, as captured in the note "Students overall are getting frustrated with the challenge". This suggests that the activity's complexity may have been overwhelming for some participants, potentially affecting their motivation. However, the field notes also provide several practical insights into how to overcome some of the challenges with implementing microelectronics content and experiences in K–12 technology classrooms:

- **Scaffolding Troubleshooting**- Students seemed to work well when they had structured "debug sessions" after initial builds. Allocating dedicated class time for small-group peer coaching—guided by a troubleshooting checklist—prevented frustration and reinforced circuit theory.
- **Pacing to Accommodate Students with Different Educational Backgrounds**- Learner familiarity with breadboarding and basic coding varied widely. Early lessons need flexible extension activities for advanced students and simplified "mini-projects" for novices to build confidence before moving to PCBs or microcontrollers.
- **Real-World Contexts to Drive Engagement**- The client-letter approach seemed to spark ownership of learning: students repeatedly referenced their "contract" when asking technical questions. When letters included photos or short video messages from a fictitious company engineer, motivation and on-task behavior improved noticeably.
- **Hands-On Tool Access and Management Matter** - Shared equipment (soldering irons, multimeters, micro:bits) required clear stations and sign-out protocols. Early field notes showed lost components and safety delays; later iterations resolved this with labelled toolkits and a rotating equipment monitor role.
- **Peer Collaboration can Strengthen Learning** - Structured roles within teams (e.g., "circuit architect," "code integrator," "quality tester") could help with equal student participation. Rotating roles each lesson can help ensure that all students experience both hardware assembly and software debugging.
- **Reflection Deepens Understanding-** Field notes show that end-of-unit debrief letters back to the client—articulating trade-offs, unexpected failures, and proposed improvements—helped to solidify technical concepts and professional communication skills.
- **Integration with Other Subjects can Add Value** - Classes that paired the microelectronics units with math (Ohm's Law calculations) or art (PCB aesthetic designs) provide interdisciplinary conversations and maybe broader student buy-in.

These lessons informed iterative refinements to the units, lesson pacing guides, and support materials, to better create a microelectronics curriculum that balances technical depth with real-world relevance.

3.3. How do secondary teaching teachers reconcile workforce imperatives with broader educational goals?

Overall, the technology teachers developed five instructional units intentionally integrating microelectronics, while aligning classroom activities with relevant industry concepts. These units are designed to help students build a foundational understanding of microelectronics principles while engaging in hands-on experiences. Beginning with basic concepts of electricity and circuits, the units guide students through the study of microelectronics and extend their thinking to broader issues, such as sustainable semiconductor supply strategies. These instructional activities can reflect the demands of emerging technologies and evolving industry needs. Through these units, students are positioned to learn what microelectronics are, how they are applied in modern society, and their impact on industries and communities. Moreover, these curriculum units may allow students to critically think by encouraging the consideration of the role microelectronics has in addressing global challenges and technological innovation. The units also are set to require students to explore problem solving processes like those used in industry to identify problems, design solutions, and implement solutions. Students engage in constructing electronic components and learning to control them through programming, practices and skills that can mirror industry activities. By bridging relevant concepts and practical skills, the curriculum can be positioned to help prepare students for understanding the microelectronics field.

Furthermore, the preliminary findings suggest that technology education's inherently flexible curriculum and hands-on approach to learning can accommodate emerging STEM workforce trends (e.g., microelectronics), potentially motivating student interest through real-world design and problem-solving activities. At the same time, the push to meet immediate workforce demands can raise questions about maintaining the subject's broader educational aims. Educators will likely need to reconcile their curriculum's design-based culture with industry/policy pressures that may prioritize technical competencies, highlighting the importance of reflective practice in teaching and curriculum development.

4. DISCUSSIONS & RECOMMENDATIONS

This preliminary study reviewed the development and implementation of a microelectronics unit in K–12 technology classrooms, exploring how teachers integrated emerging, industry-relevant content into authentic educational contexts. One implication to ponder is the evolving identity of technology education as it responds to workforce demands (Hacker, 2023; citation omitted). While integrating industry-specific content can engage students in authentic learning, it can risk narrowing technology education into vocational training focused on immediate job preparation. This idea reflects ongoing debates over whether technology education should primarily promote workforce readiness or foster broader creativity, design thinking, and lifelong learning. This preliminary case study also highlights the differences in readiness for microelectronics and access to resources across schools, particularly between rural and suburban contexts. Ensuring all students have meaningful opportunities to engage with emerging technologies is important to continue through educational programming. However, the preliminary results suggest some

actionable ideas for practice. For example, curriculum developers can use the examples provided here to design units that can be flexibly implemented and scaffolded to meet different student and community needs, while embedding authentic, real-world problem contexts to promote engagement through instructional tools such as client letters (McDonnell et al., 2025). Teacher professional development could prioritize upskilling content and pedagogy, foster communities of practice for sharing resources, and build partnerships with industry for current knowledge and support. Policy and leadership could provide support, such as flexible scheduling and industry connections to ensure that classrooms are aligned with workforce needs.

5. CONCLUSION

This preliminary study explored how secondary technology teachers developed and implemented microelectronics instructional units to integrate emerging industry-relevant content into authentic classroom contexts. The preliminary results demonstrate both the opportunities and "lessons learned" of such integration. While the units seemed to engage students in authentic, hands-on problem solving and introduced them to more advanced technological concepts, it also revealed a possible risk of narrowing technology education toward vocational training. These results can reveal a need to discuss the balancing of industry-specific content with the broader, design-based mission of technology education, helping to ensure that students develop creativity, critical thinking, and adaptability alongside specific technical knowledge. They also suggest the importance of designing adaptable curricula, supporting teacher capacity through targeted professional development and industry partnerships, and aligning policies to sustain the breadth and relevance of technology education. By addressing these considerations, educators and policymakers could help better ensure that technology education remains responsive to evolving workforce needs while preserving its essential role in fostering holistic student growth and lifelong learning.

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Navigating the Motivational Rollercoaster of Long-Term Engineering Design Projects

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Abstract

Design-based learning, a hallmark of technology education and STEM integration, offers students dynamic, open-ended challenges that can spark high levels of initial engagement. However, motivation can fluctuate significantly over the course of more, larger-scale or long-term design projects, as learners encounter design realities including ambiguity, iterative processes, and the demand for meaningful outcomes. These "highs and lows" of engagement – analogous to a motivational rollercoaster – can deter students from persisting through difficult stages, thereby reducing the potential impact of the project on learning, skill development, and producing valuable design outputs. This paper examines some key factors that can influence motivational fluctuations in long-term design projects, drawing on existing design education literature and principles from transitional psychology. In particular, Schlossberg's Transition Theory will be reviewed as a useful lens for understanding the emotional journey students experience when moving from initial enthusiasm in designing to potential crisis points characterized by discouragement and uncertainty. The theory's 4S framework – Situation, Self, Supports, and Strategies – can offer practical guidance that can be translated to education to help students recognize and navigate these transitions in motivation and engagement. Additionally, this paper reviews specific strategies that can mitigate motivational challenges, including designing empathy-driven tasks that enhance personal relevance, providing clearer milestones to reduce ambiguity, and delivering actionable feedback. By acknowledging the role of motivation in design projects and equipping students with coping mechanisms for setbacks, educators can create more supportive, resilience-building environments. Ultimately, this literature review sought to highlight the importance of discussing the motivational rollercoaster inherent in design education, offering insights for practitioners and researchers to enhance student persistence, engagement, and the overall quality of design-based educational experience.

Key Words: Design Education, Motivation, Transition Theory

1. INTRODUCTION

Student engagement plays a pivotal role in determining educational outcomes, particularly in engineering disciplines at the introductory college levels. While very broad, the term engagement encompasses several key attributes: students' behavioural participation, emotional connection,

and investment in their learning processes (Fredricks, Blumenfeld, & Paris, 2004). High levels of engagement have been consistently linked to improved academic performance, deeper understanding, development of critical engineering skills, and higher retention rates in engineering fields (Chen, Lattuca, & Hamilton, 2008; Simmons, Ye, Ohland, & Garahan, 2018). However, despite its recognized importance, maintaining sustained engagement throughout long-format engineering design projects presents educators with considerable challenges.

Long-format engineering design projects typically span several weeks up to an entire academic term and are developed to mimic authentic engineering experiences, similar to industry experience. They require students to engage deeply in problem-solving, critical thinking, collaboration, and the engineering design process, aspiring to mirror real-world engineering scenarios. Such projects offer students valuable hands-on experiences, preparing them for professional engineering practice. These experiences become ever more important for students who have never participated in engineering curriculum. While many students may have had opportunities for introductory engineering courses in high school, this is not the standard. Many high schools, including academically advantaged ones, do not offer any courses examining the engineering design process. For this reason, introductory engineering design courses must accommodate both students who have significant experience with engineering principles, acquired from high school curriculum or academic clubs, in addition to students wholly unfamiliar with the engineering design process. Nevertheless, these extensive projects can pose significant challenges, including decreasing motivation over time, ineffective collaboration among students, insufficient instructor interactions, and poorly structured project designs that fail to maintain student interest (Dawes & Senadji, 2010; Carpenter, Yakymyshyn, & Micher, 2016).

Research indicates that students often experience declining motivation due to monotonous or unclear tasks, social loafing within teams, limited interaction with faculty, and the perception of project irrelevance or impracticality (Chen, Lattuca, & Hamilton, 2008; Kuester & Griesemer, 2024). Consequently, it is necessary for educators to identify and implement effective strategies that sustain student engagement, ensuring that the educational benefits of long-format design projects are fully realized.

This literature review addresses the following research question: "How can instructors encourage continued student engagement in long-format engineering design projects in introductory college courses?" Four critical dimensions of long-format engineering projects were selected for review: pedagogical strategies, group collaboration and team dynamics, instructor engagement, and project design considerations. These four categories were identified based on consistent themes emerging from the literature as well as the breadth of coverage they provide for investigating these types of projects. Considered as a whole, they encompass diverse viewpoints, thereby offering a more comprehensive account of the factors influencing student experience. Sustained success across these areas has the potential to significantly enhance both learning outcomes and student engagement in design-based education.

2. LITERATURE REVIEW

2.1. Long Term Design Projects and Motivation

When students begin a long-format design project, they often begin with great enthusiasm; a strong sense of excitement, motivation, and energy accompanied by the unfamiliar academic venture. However, throughout the design process, challenges are sure to arise causing students to encounter crisis points marked by discouragement, self-doubt, and uncertainty. These emotional highs and lows are akin to a transition: a psychological process of adapting to change. Nancy Schlossberg spent much of her career investigating these transitions, developing her Transition Theory to describe the factors relevant to these transitions (Schlossberg, 1981). Her 4S framework (Situation, Self, Supports, and Strategies) provides a helpful explanation for how individuals experience and manage transitions in their lives, or in this case, how students navigate the motivational highs and lows of long-format design projects. This model has since expanded and been applied across diverse counselling contexts, providing even greater applicability to real-world implementation (Anderson, Goodman, & Schlossberg, 2012).

The first S, Situation, refers to what is triggering the transition and the context in which it occurs. In this case, that is the shift from initial optimism and excitement to a setback, such as a failed prototype, unclear expectations, or critical feedback on the project. Self, the second S, describes the personal characteristics that influence how a student copes with these transitions. This could be related to their confidence in their abilities, previous experience in the field of design, growth vs. fixed mindset, resiliency, or their own identity as a learner. A student with a strong mindset regarding struggle may view challenges as a chance to grow, while others may feel overwhelmed. Supports are the resources and relationships available to help students through the transition. Whether this be feedback from instructors, peer collaboration, mentorship, or institutional resources like tutoring or mental health support, a student with a strong social support system is more likely to persevere through difficult chases of a project. Finally, Strategies identify the coping mechanisms students use to manage transitions. This may be as simple as seeking help, time management, or reevaluating goals. However, simplicity does not imply ease. While seemingly simple, many students instead use unproductive strategies like avoidance, disengagement and excessive self-criticism, as they are often easier than facing the productive pathways of strategy.

While the third S, Support, may seem the most obvious as to where educators can ease the burden of students moving through transitions in their design projects, all aspects of the 4S Framework can be affected by teacher influence. Educators can ease situational struggles, thereby preventing some transitions from occurring, by setting clear expectations and structured timelines so students know what to anticipate. Normalizing struggle by sharing common design or learning roadblocks and framing them as necessary for growth can also help to smooth friction points. For Self, encouraging a growth mindset [i.e., the belief that your capabilities can be developed through effort and learning (Dweck, 2017)] and highlighting student strengths, especially when confidence wanes, can help to prevent students who would otherwise disengage, stay motivated. Additionally, offering self-reflection opportunities such as journals or check-ins is an effective way to help students assess their emotional and motivational state. As stated previously, one of most clear areas for educator intervention is in Supports. Educators can ease these struggles by

facilitating a supportive classroom culture where peer feedback is constructive and collaboration is encouraged, not looked down upon. Additionally, as an educator, being accessible and empathetic by maintaining interest in student projects, showing care, and offering guidance can ease many challenges that students will face. Finally, Educators can potentially mitigate Strategy-related challenges by helping students develop adaptive practices such as goal setting and time management. Additionally, providing feedback that is actionable and timely can encourage re-engagement from disengaged students, as well as strengthening the motivation of engagement-waning students. To provide an additional analogy alongside that of the motivational rollercoaster, the task of an educator can be thought of as a Transition Guide, helping students along an unknown path. Educators can guide students through making sense of emotional ups and downs as well as help to develop the personal and interpersonal resources to keep going. When applied intentionally, Schlossberg's framework empowers instructors to proactively support student motivation and engagement, rather than just reacting after a crisis point. Moreover, the four dimensions identified for this review: pedagogical strategies, group collaboration and team dynamics, instructor engagement, and project design considerations, can be understood as practical avenues through which the principles of the 4S framework are enacted. Each dimension aligns with aspects of Situation, Self, Supports, and Strategies, providing a structured lens for examining how instructors can influence student engagement in design-based education.

2.2. Critical Dimensions of Motivation and Engagement

2.2.1. Pedagogical Strategies

Many educators recognize that pedagogical strategies can influence students' ongoing engagement, particularly when active learning techniques are used. Active learning methods, such as project-based learning (PBL) or design-based learning (DBL), engage students in practical and meaningful tasks (Smith, Sheppard, Johnson, & Johnson, 2005; Wells & Van de Velde, 2020). Williams and Capraro (2017) demonstrated that such pedagogical approaches can increase student engagement by integrating rigorous academic content with real-world scenarios, thus making learning relevant and exciting. The existence of clear applicability to real-world problems helped to maintain student interest in classroom activities. Reynolds, Mehalik, Lovell, and Schunn (2009) reinforced these findings by showing that high school students engaged in DBL projects displayed heightened interest in engineering careers. This increase in interest resulted from the authentic, practical experiences that allowed students to see the real-world applications of their classroom knowledge. Similarly, Watterson, Browne, and Carnegie (2013) observed increased student retention and engagement in introductory engineering courses that included hands-on design projects. These practical activities provided meaningful connections between theoretical knowledge and practical applications, reinforcing students' intrinsic motivation. Hands-on design projects can significantly increase the intrigue of students, thereby making them more likely to maintain active involvement.

Structured peer assessments are another effective pedagogical approach for maintaining student engagement. Dawes and Senadji (2010) highlighted that clearly defined expectations within peer assessment processes can reduce confusion and sustain student accountability throughout extended projects. Additionally, Carpenter et al. (2016) demonstrated that structured formative feedback and clear instructional guidance significantly increased student engagement and reduced confusion over long-term tasks.

2.2.2. Group Collaboration and Team Dynamics

Effective group collaboration and healthy team dynamics are essential to sustaining student engagement during extended engineering projects. Dawes and Senadji (2010) emphasized that well-defined roles and structured peer evaluations reduce conflict and social loafing, enhancing accountability and sustained participation. However, it was also concluded that specifically appointing a group leader or having entirely male groups could have detrimental effects to student performance (Dawes and Senadji, 2010). When group roles are explicitly outlined, students better understand their responsibilities, which fosters continuous engagement.

Carpenter et al. (2016) reinforced this point by demonstrating that individual accountability within team structures significantly reduced social loafing. Each student's distinct responsibilities were clearly articulated, ensuring equal contributions and maintaining high levels of engagement. Herrero, Giralt, Medir, and Grau (2000) introduced vertical mentorship, in which senior students mentor first-year students. This mentorship approach improved freshmen students' engagement by providing peer support, mentorship, and clear accountability to a more experienced individual within the team structure.

Moreover, intentional group formation strategies are important for enhancing group effectiveness. Dawes and Senadji (2010) found that teams deliberately selected by instructors, based on student skills and diversity, performed better than randomly assigned or self-selected groups. Herrero et al. (2000) found that regular peer evaluations allowed for open communication, transparency, and accountability, which reduced conflict and improved team cohesion.

2.2.3. Instructor Engagement

Instructor engagement is vital to sustaining student involvement throughout extended engineering projects. Chen et al. (2008) emphasized the importance of consistent and meaningful instructor interactions, mentorship, feedback, and visible enthusiasm. Proactive instructor involvement significantly influences student motivation and ongoing design project participation. Carpenter et al. (2016) supported these findings, demonstrating that regular instructor feedback and personalized guidance were essential for keeping students engaged. Proactive instructor engagement was shown to help students navigate design project challenges and maintain motivation by evoking a leading-by-example method of instruction. Similarly, Kuester and Griesemer (2024) found that instructors who consistently monitored student progress, adapted instructional methods based on feedback, and provided timely interventions achieved greater student retention and sustained engagement.

Simmons et al. (2018) also highlighted instructor-student interactions as critical for overcoming barriers such as time management and external responsibilities. Regular interactions and personalized attention helped students remain committed and engaged despite these external pressures. Continuous instructor support, including motivational encouragement and targeted feedback, thus plays a significant role in sustaining student engagement while being an easy-to-implement change.

2.2.4. Project Design Considerations

Project design significantly affects student engagement in extended engineering tasks. Effective design projects should be relevant to real-world problems, appropriately challenging, and

structured with clear milestones. Kuester and Griesemer (2024) stated that structured milestones combined with regular feedback sessions are essential for keeping students consistently engaged. Clear checkpoints provide students with motivation and help instructors offer timely assistance when needed.

Watterson et al. (2013) emphasized the importance of project relevance by demonstrating increased student motivation when tasks were directly related to authentic engineering problems. Real-world projects help students appreciate the significance of their learning, leading to sustained cognitive and emotional investment.

Carpenter et al. (2016) further advocated for creative autonomy within structured guidelines. By allowing students to express creativity and personalize their solutions, engagement can be significantly increased. Williams and Capraro (2017) noted that integrating competitive elements or public showcases into projects provided additional motivation, encouraging students to remain continuously engaged by promoting a sense of accomplishment and recognition. Additionally, Dawes and Senadji (2010) found that clear communication of project expectations, objectives, and evaluation criteria significantly reduced confusion and maintained engagement. When students clearly understood what was expected, they were less likely to disengage due to ambiguity or frustration.

2.3. Conclusion

Maintaining student engagement throughout long-format engineering design projects requires a strategic integration of effective pedagogical strategies, structured group dynamics, proactive faculty engagement, and thoughtful project design. Each dimension provides a unique contribution to sustaining student motivation and participation. Pedagogically, methods such as active learning, PBL, and DBL create engaging environments by linking theory to practice, thus increasing relevance and student investment. Structuring group dynamics by including clearly defined roles, intentional group formation, and regular peer assessments, ensure continuous and equitable participation among students. This helps reduce the likelihood of disengagement through frustration or social loafing. Instructor engagement can be a significant contributor to student motivation, with consistent instructor involvement, ongoing mentorship, and timely feedback serving as powerful motivators for sustained student effort. Proactive instructor interventions and regular interactions help students navigate challenges, maintain confidence, and develop deeper connections to their design projects and the engineering discipline overall. Finally, carefully crafted design project structures can enhance sustained engagement. By developing design projects that are authentic, challenging yet achievable, structured – with clear and frequent milestones, and provide students with autonomy and opportunities for creativity, student motivation can be elevated. Clearly communicated expectations and objectives can further ensure students remain focused and committed throughout the design project's duration.

Educators who integrate these strategies can significantly increase student engagement. This should lead to improved academic outcomes, greater skill development, higher student satisfaction, and increased retention in engineering design courses. Future research could potentially focus on longitudinal studies evaluating the long-term impacts of these integrated

strategies on student success in design coursework, potentially providing deeper insights into the sustained benefits of effectively crafted long-format design projects.

3. DISCUSSION

While often discussed as if it is a fixed endpoint, student disengagement can better be thought of as a transitional phase, as described by Nancy Schlossberg (Schlossberg, 1981). The motivational rollercoaster experienced by many students during long-format design projects mirrors Schlossberg's concept of psychological transitions. Therefore, describing student experiences in these projects with the 4S framework can be a very useful tool for instructors to better prepare students for challenges, as well as resolve them. By acting as a sort of "Transition Guide", as previously discussed, educators can facilitate higher levels of engagement and motivation over the course of design projects, as well as proactively solve motivational struggles. In each of the 4S elements, there are many options for instructors looking to improve student experiences. For Situation, developing structured timelines, setting expectations early, and normalizing struggle can help prevent many motivational transitions from occurring. Regarding Self, instructors should encourage student reflection, help to develop a growth mindset, and highlight student successes. For Supports, fostering a collaborative community, offering guidance for students, and encouraging peer feedback are all good ways to develop a robust support system for students. Finally, making students aware of, and encouraging use of coping tools like time management, goal setting, and help-seeking are all ways to mitigate strategy-based challenges.

The literature affirms this view, highlighting that structured design projects, intentional team formation, and ongoing instructor presence are among the most effective interventions. These elements collectively align with Schlossberg's theory by ensuring that students have the tools, relationships, and context necessary to weather the motivational turbulence of long-term design work. Furthermore, pedagogical approaches that offer authentic engagement while reinforcing real-world relevance of the material, can help to enhance student buy-in and commitment.

While there are many opportunities for instructors to encourage student engagement, there are many related tensions in this area. The integration of structured timelines also reduces student autonomy. Encouraging group and peer collaboration can often decrease individual accountability. Effective instructional design must strike a balance between these dimensions to keep students challenged, but supported, and creative, but prepared. Therefore, future research should explore how intentional integration or transitional psychology and Schlossberg's 4S framework into curriculum design could enhance engagement outcomes across disciplines. Longitudinal studies that track student trajectories across multiple design projects would be valuable in identifying when and how motivational transitions most commonly occur, as well as which interventions have the greatest effect. While the task of a Transition Guide can seem daunting, there are many small adjustments educators can make to enhance student motivation and outcomes.

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Functional Thinking in Elementary Students: Exploring Motion Concepts Through Robotics Education

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Abstract

This exploratory and collaborative study, conducted in the first and second cycles of elementary school, investigates the potential of educational robotics (LEGO Spike Essential) to foster functional thinking and introduce students to the technological design process. In partnership with two techno-pedagogues and a mathematics education advisor, we designed motion-based tasks inspired by Galileo's work on variation, aiming to explore the simultaneous variation of two quantities during the robot's movement. The theoretical framework integrates Early Algebra (generalization before formalism), covariational reasoning (how one quantity changes with another), and a multisemiotic perspective (gestures, traces, measurements, tables, language) informed by representation registers (Duval, 2006). The experiment took place in a multi-grade classroom in a rural school in Northern Quebec (15 students). The tasks, with fixed speed or time, required students to predict the robot's position, then measure the actual position and examine the discrepancy. A series of indicators tracked how students progressed from local understanding—such as comparing values or observing simple variations—to more global comprehension, including general rules and concepts like rate. This progression was supported by adjustments and corrections guided by discrepancy analysis. Preliminary results show: (i) explicit directional covariation, (ii) successful interpolations and extrapolation, (iii) variable control ("we change the time, not the speed"), (iv) signs of constant rate at fixed speed, and (v) instrumented verifications using a meter with hesitations around decimals. The prediction–execution–revision loop emerges as a driver of learning and classroom engineering. The study highlights functional thinking trajectories in elementary education that are still under-documented and opens avenues for analyzing other teams and designing setups that reinforce rate quantification and semiotic orchestration.

Key Words: functional thinking, educational robotics, elementary education, covariational reasoning, semiotic orchestration

1. INTRODUCTION

Educational robotics represents a promising lever for fostering early forms of mathematical thinking in elementary education, particularly functional thinking, which focuses on the

dependency relationship between quantities and covariation. In this exploratory study conducted in the first and second cycles of elementary school, we analyze motion-based tasks using a LEGO Spike Essential robot, inspired by Galilean studies of uniform and accelerated motion. These tasks aim to simultaneously support students' initiation into the technological design process and their understanding of functional ideas prior to their formal introduction in secondary education.

Recent systematic reviews and meta-analyses highlight generally positive effects of integrating educational robotics into STEM skill development. However, these effects are highly dependent on the quality of the didactic orchestration implemented and the duration of students' exposure to the learning environments. This framework particularly encourages engagement in tasks involving measurable variations that can be modeled.

2. PROBLEM STATEMENT

In secondary education, learning about functions often encounters persistent challenges. On one hand, students' perception of covariation between two quantities remains fragile—they struggle to understand "how y changes when x changes" and to connect this covariation to graphical representations (e.g., in Grade 8). These difficulties are well-documented in research on the development of covariation concepts and the use of graphs (Passaro, 2007). On the other hand, students face major obstacles when transitioning between different representation registers (language ↔ table ↔ diagram/graph ↔ expressions), which hinders their understanding of functional relationships. Duval (2006) emphasizes that these register conversions are central to comprehension issues in mathematics.

Introducing functional thinking early—through tasks that make variation visible and orchestrate register conversions—aims to prevent these difficulties, stabilize relational invariants (dependency, rate), and lay the groundwork for formal algebra.
In elemetary education, pattern-based sequences support recursive generalization but address less directly the input–output dependency and rate of change. Reviews focused on elementary education highlight the potential of robotics-based activities to develop STEM and mathematical skills, while also noting a lack of studies that explicitly target concepts such as variation and function, and their semiotic documentation.

Indeed, recent reviews and meta-analyses suggest positive effects of robotics on STEM competencies, provided that there is effective didactic orchestration (teacher support, pedagogical strategy, type of interaction) and sufficient exposure time—a context conducive to tasks involving measurable and modelable variation (Ouyang & Xu, 2024; Trapero-González et al., 2024; Wang et al., 2024). More specifically, Ouyang & Xu show that the overall effect is positive, and moderated by variables such as instructor support, teaching strategy, and intervention duration—factors that condition the success of robotics-based learning environments (Ouyang & Xu, 2024).

Syntheses focused on elementary education confirm the didactic value of robotics for STEM skills and emphasize the quality of orchestration (task structure, guidance, timing) (Trapero-González et al., 2024), while other meta-analyses also highlight attitudinal gains and positive effects, though variable depending on evaluation and implementation modalities (Wang et al., 2024).

These findings underscore the need to analyze how elementary students engage in functional thinking within robotics tasks where variation is made visible and measurable.

Research Question: How do modes of functional thinking emerge and evolve in elementary students during robotics-based tasks?

3. THERETICAL FRAMEWORK

Our theoretical framework is built upon three complementary foundations to examine how functional relationships manifest in mathematics learning during robotics activities in elementary school. First, we consider functional thinking—defined as the ability to establish dependency relationships between quantities, identify correspondences, and formulate rules—as a gateway to algebraic thinking. Second, we draw on covariational reasoning, which involves examining how one variable changes in relation to another ("how y changes when x changes"), envisioning a progression from qualitative to quantitative understanding, particularly through the gradual introduction of the concept of rate. Third, we adopt a multisemiotic perspective, emphasizing the coordination of representation registers (spoken language, gestures, written traces, measurements, tables, diagrams, and graphs) and the conversions between these registers, which are essential for developing a deep understanding of functional relationships.

3.1. Functional Thinking

We define functional thinking as the ability to reason about relationships between quantities that vary together, to anticipate values, and to express dependency rules prior to symbolic formalization. Covariational reasoning—describing "how y changes when x changes"—plays a central role in this process.

The model proposed by Pittalis, Christou, and Pitta-Pantazi (2020) outlines four interrelated dimensions, representing distinct but connected ways of thinking about relationships between quantities:

(i) Recognition and extension of patterns (recursive patterning
(ii) Understanding simultaneous variation of two quantities (covariational thinking)
(iii) Identification of pointwise correspondences between given values (correspondence–particular)
(iv) Generalization of these correspondences into rules or formulas (correspondence–general)

Together, these dimensions trace a cognitive progression from local and perceptual reasoning to more abstract and generalized forms, providing a framework for designing tasks that foster functional thinking from the early years of schooling.

3.2. Covariational Reasoning and Multisemiotic Perspectives

In this perspective, Robert (2024) highlights key moments of conceptualization linked to multisemiotic deployment in the classroom (gestures → inscriptions → verbal statements) and shows how covariational reasoning serves as an entry point into functional thinking. These moments often involve observable shifts, where understanding takes a qualitative leap through semiotic conversions.

Understanding a functional relationship thus requires that students mobilize and coordinate multiple semiotic registers. According to Duval (2006), this involves both intra-register processing (transformations within a single sign system) and inter-register conversions (e.g., from table to graph), which are crucial for meaning-making in modeling.

The work of Arzarello & Robutti (2008) and Radford (2010) enriches this analysis by integrating gestural, verbal, and material dimensions, showing that semiotic activity is embodied and distributed across artifacts, language, and actions. A multisemiotic approach thus sheds light on how students weave together representations to access abstract concepts and stabilize their understanding of dependencies between quantities.

Research Objectives:

(i) Identify indicators of emerging functional thinking during robotics-based motion tasks in elementary education.
(ii) Analyze the role of semiotic resources in processes of justification, prediction, and modeling.
(iii) Document the difficulties encountered by students, particularly regarding context selection, rate stability, and register conversions.

4. METHODOLOGY

4.1. Participants and Organization

The experiment was conducted in a multi-grade classroom (1st and 2nd cycles) in a rural school in Northern Quebec (ages 7–8). A total of 15 students, organized into pairs, participated in the study. Five adults (research team and classroom teacher) supervised the pairs, asked questions according to the established protocol, and ensured audio/video recording.

4.2. Technological Design Process and Data Corpus and Collection

In this sequence, design is approached as a problem-solving engineering process, structured in stages: problem identification → ideation → prototyping → testing/measuring → iteration → optimization. Three corridors were used to guide the robot's path. The instructions required a series of trials at constant speed with variable time (and vice versa), predictions through prior marking [PRED], followed by instrumented verifications [MES] using a measuring tape.

The “motion” anchor concretizes double variation and enables comparisons of discrepancies (local quasi-linearity). This approach compels students to articulate their reasoning, instrument their measurements, and adjust their procedures, thereby promoting the progressive formalization of mathematical rules such as $d \approx k \cdot t$ for a given speed. Design thus becomes a powerful lever for integrating scientific thinking, problem-solving, and mathematical modeling.

The analytical corpus is based on a triangulation of data combining material traces and audiovisual recordings. The traces left by students on the corridor—especially the marks associated with predictions ([PRED]) and measurements ([MES])—document the discrepancies between anticipation and observation. Distances (in centimeters) and durations (in seconds) were recorded on task sheets, providing a basis for analyzing reasoning and adjustments.

Audio and video recordings (three vignettes per team) from the sessions (including interviews) offer rich material for studying interactions, verbal justifications, and group dynamics. Adult observations, recorded vocally during the sessions, complement this setup. Finally, digital artifacts produced by students—particularly programming scripts and LEGO Spike robot parameters (speed in %, duration in seconds)—were not included in the data analysis presented in this article.

4.4. Observable Indicators and Analytical Framework

Based on the theoretical framework, we identified observable indicators (actions/statements/productions) that reflect the emergence of functional relationships and covariational reasoning, in connection with semiotic registers.

Table 1.
Observable Indicators and Their Manifestations

Theoretical Axis	Indicators	Manifestations
Functional Thinking/Early Algebra	I1 – Local covariation I2 – Controlled variable comparison I8 – Multiplicative invariants I9 – Relevant variable control	Reasoning about relationships between variables prior to formalization. Distinction between operations (× vs +). Experimental control.
Covariational Pivot	I3 – Qualitative rate I4 – Anticipation I5 – Global rule I6 – Rate quantification	Transition from perceived rhythm to quantification. Emergence of proportional rule. Construction of unit rate.
Registers and Conversions	I5 – Global rule I6 – Rate quantification I7 – Calibration and units	Coordination among gestures, language, diagrams, tables. Stabilization of procedures and units.
Semiotic Objectification	I10 – Metacommentary on the rule	Transition from gesture to inscription to verbal statement. Verbalization of generalizations.

Engineering / Design	I11 – PER loop	Iterative process in educational robotics: prediction, execution, revision.
Specific Operationalization	Task principle	Use of [PRED]/[MES] marks, Δ calculation, tolerance adapted to elementary level.
Non-linear Progression	Transversal (episode coding)	Co-coding of achieved levels; triangulation of data (verbal, trace, gesture, measurement).

We integrated algebraic thinking, particularly in its functional form, to enhance the precision of data analysis and interpretation. This mode of thinking enables students to reason about variable relationships before any symbolic formalization. Robotics-based tasks, structured around the [PRED] → [MES] → Δ setup, make variation visible, support anticipations, and foster the construction of regularities such as $d \approx k \cdot t$. The orchestration of semiotic registers (gestures, language, diagrams, tables) facilitates both generalization and rate characterization. The analysis thus relies on a dual focus: algebraic for generalization and justification, and functional for covariation, anticipation, rule formulation, rate, and variable control.

Audio and video recordings are segmented into analysis units, or episodes (≈30–120 seconds), during which the team explicitly addresses the time–distance relationship. We apply the "highest level reached" principle, with co-coding of lower levels to capture progression. The analysis is based on triangulation of sources (verbal, traces/measurements, gestures).

For I4 (anticipation) and I6 (rate), a tolerance is set for the discrepancy Δ = MES – PRED, at 10–15% of the measured distance, to distinguish coherent predictions from random placements. A coding journal records the type of adult prompt immediately preceding the episode (prediction, justification, comparison, generalization), to document the orchestration of learning.

5. PREMINILARY RESULTS AND DISCUSSION

As data analysis is ongoing, we present here some preliminary findings from four analytical units corresponding to vignette 8.1 (Grade 2). These initial results partially address the research question posed in Section 2 by documenting concrete manifestations of functional thinking in elementary students.

Observations from vignette reveal a typical progression of functional thinking in elementary education, moving from local observations of directional covariation (I1) to more structured anticipations (I4) and the emergence of a global rule at fixed speed (I5), approximating $d \approx k \cdot t$. These indicators align with the dimensions described by Pittalis et al. (2020), reflecting a cognitive shift from perceptual to generalized reasoning. This trajectory also confirms that the relationship between two quantities (time, distance) can be explored well before the formal introduction of the function concept, in the spirit of early algebra, which emphasizes generalization before formalism.

The combined use of semiotic resources—pointing gestures, floor markings, measurements in centimeters, verbal statements—plays a decisive role in objectification and register conversion. Midpoint placements to predict where the robot should stop based on the given number of

seconds, ordinal justifications (“it’s 2 more”), and instrumented verification using a measuring tape illustrate a circulation between trace ↔ language ↔ measurement, conducive to stabilizing the correspondence between variables.

Minor errors in spacing and hesitations around decimals indicate known fragilities in register-to-register conversions and suggest the need to reinforce work on units and calibration (I7). However, these fragilities are expected and should be interpreted in light of the curricular progression in elementary education.

For measurement, the Progression of Learning (PDA) first introduces estimation and measurement using non-standard units, followed by the gradual introduction of standard units (meter, decimeter, centimeter); consistent use of instruments (graduated ruler, fine calibration) is therefore only fully expected over time, which explains the occasionally approximate “midpoint” placements on the floor.

For decimal numbers, the PDA explicitly organizes a gradual introduction: representation, reading/writing, understanding of the decimal point, placement on the number line, and comparisons are emphasized in the second cycle (up to hundredths, then thousandths), before consolidating calculation procedures (written/mental) in the third cycle. The observed hesitations regarding decimal discrepancies or midpoint verification using a measuring tape are thus expected in early-cycle students: they reflect knowledge under construction, rather than a lack of understanding of functional relationships.

In summary, our motion-based tasks engage components (precise instrumentation, decimal management) that stabilize progressively according to the PDA; it is therefore coherent to observe tolerated discrepancies, recalibrations, and still proto-quantitative justifications of rate prior to robust mastery.

From the perspective of covariational reasoning, we observe a shift from qualitative rhythm (I3) to proto-quantification of rate (I6), when students anticipate approximately constant discrepancies at fixed speed. This development corresponds to the milestones described by Thompson & Carlson (2016), where understanding “how y changes when x changes” precedes and supports the formalization of a constant rate. Additionally, the statement “we’re changing the number of seconds, not the speed” explicitly demonstrates relevant variable control (I9), a necessary condition for reasoning about dependency.

Finally, the [PRED] → [MES] → Δ loop (I11) proves to be fruitful: it establishes a cycle of anticipation–confrontation–revision that simultaneously supports generalization (algebraic focus) and characterization of dependency (functional focus). The results support the idea that tasks involving measurable and modela variation promote the articulation between algebraic and functional thinking, provided that orchestration makes invariants (dependency, rate) visible and supports semiotic conversions.

5. CONCLUSION

In summary, these preliminary results are promising regarding the relevance of exploring motion concepts through educational robotics as a means to foster functional thinking in elementary education. The [PRED] → [MES] → Δ setup and the I1–I11 indicator grid provide a detailed framework for documenting the emergence of functional thinking aligned with early algebra, while also making visible the semiotic conversions and instrumented adjustments expected at the elementary level (PDA).

Findings related to directional covariation, interpolation/extrapolation, and signs of a constant rate at fixed speed appear consistently in the analyzed vignette and offer a solid analytical foundation for further investigation. However, these findings must be expanded and refined through the analysis of additional vignettes (teams and corridors), which will allow for triangulation of indicators (I1–I11), clarification of orchestration conditions (prompts, supports, Δ tolerances), and identification of progression profiles.

The complete results will be presented in a structured publication (including consolidated coding tables and didactic implications), with the aim of sharing the outcomes and limitations of the study with the scientific community—and opening avenues to strengthen rate quantification and the semiotic anchoring of motion-based tasks in elementary education, particularly in STEM and robotics contexts.

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A Retake on Research Agendas: Does Graduate Research Fill the Need?

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Abstract

The *Technology Education Graduate Research Database 1892-2000* (TEGRD; Reed, 2001) built upon the work of Jelden (1981) and Foster (1992) and lists over 5,200 dissertations and theses. The TEGRD highlights the history of doctoral dissertation, educational specialist, and master's research in technology and engineering education, much of which goes unpublished. A review of technology and engineering education graduate research has not been shared since Foster (2010). This paper will focus on graduate research from 2000-2024 as a comprehensive update to the TEGRD. Methods used to build the database will be shared as well as common themes that emerged in the past 25 years and comparisons to published calls for research during this period (i.e., Cajas, 2000; Lewis, 1999; Martin & Ritz, 2012; Williams, 2011).

Key Words: Graduate research, trends and issues, research agendas.

INTRODUCTION

There is a long history in the United States of tracking research in technology and engineering education. For over thirty years, periodic reviews of literature were conducted through funding from The Center on Education and Training for Employment (see Dyrenfurth and Householder, 1979; Householder and Suess, 1969; McCrory, 1987; Streichler, 1966; Zuga, 1994). Graduate student research has also been thoroughly tracked in technology and engineering education. Jelden (1976) documented processes for searching mainframe databases and gathering information on graduate research from university programs. Foster (1992) and Reed (2001) built on Jelden's (1981) work, and in total, they identified over 5,200 theses and dissertations spanning 1892-2000 (Reed, 2001). At least two updates on graduate research have been conducted since the creation of the *Technology Education Graduate Research Database 1892-2000* (TEGRD). Foster (2010) provided a decades-long overview of graduate research and, more recently, Rodriquez and Reed (2025) take a detailed look at the past 25 years.

One rationale for tracking research is that there are persistent calls in the literature for needed research in technology education (i.e., Cajas, 2000; Lewis, 1999; Martin & Ritz, 2012; Williams, 2011). This paper will review these calls for research to see whether graduate research conducted from 2000-2024 address the areas of need identified in the literature during that time.

LITERATURE REVIEW

Technology and engineering education has fewer teacher education programs and fewer faculty researchers than core disciplines such as science and mathematics. Despite these differences, the analysis of existing technology and engineering education research and outlines of needed research is a common theme in the literature. This section will review literature from the past 25 years that analysed existing research and made recommendations for research that could contribute to a research agenda.

Lewis, (1999) used select research examples in science, mathematics, design, and technology education to raise questions for research in technology education. Specific recommendations for research included (alphabetical order):

- Conceptions and misconceptions of technological phenomena.
- Curriculum change.
- Gender in technology classrooms.
- Integration of technology and other school subjects.
- Perceptions of technology.
- Technological literacy.
- Technology and creativity.
- The work of technology teachers.

Lewis, (1999) felt that researchers should not focus solely on these topics but should develop topics of their own focused on the classroom, students, teachers, and subject matter. He also advocates for the use of mixed methods approaches to research so the field is not limited by the questions asked or the findings.

Organizations affiliated with science, technology, and engineering education have focused on research in several ways. The International Technology and Engineering Educators Association's (ITEEA) Council on Technology and Engineering Teacher Education (CTETE) has dedicated five yearbooks to research (see Council on Technology and Engineering Teacher Education, 2025). Additionally, the National Research Council (2006) published a report that looked at assessing technological literacy. The American Association for the Advancement of Science (AAAS) also held several meetings on technology education research. Cajas (2000) detailed an AAAS meeting of thirty-five science educators, technology educators, and cognitive scientists to "raise consciousness on the needed research and to begin a discussion for a research agenda in technology education" (p. 75). Key themes that emerged included (alphabetical order):

- Educational research methods.
- Efficient and cost-effective teacher professional development.
- How teachers understand and come to understand technology.
- How well curriculum and class instruction help students learn concepts and skills.
- Student learning of key technological ideas (concepts) and skills (processes).

- Use science, mathematics, and cognition research as models and researchers in those fields as partners.

Martin and Ritz (2012) conducted a Delphi study using seventeen professors who received the Council on Technology and Engineering Teacher Education's (CTETE) Teacher Educator of The Year Award. Participants were asked to identify the most important issue that needs to be researched related to K-12 technology (and engineering) education and the results were (rank order):

(i) Impact on academic achievement.
(ii) Benefit of K-12 technology and engineering education.
(iii) Engineering content and curriculum.
(iv) Verification of content for technology and engineering education.
(v) Shortage of critical research [important to K-12 learning outcomes].
(vi) Student learning.

Additionally, Martin and Ritz (2012) asked participants to identify the most important issue that needs to be researched related to preparation for teaching this school subject. Only one recommendation was made for this research question: Cognitive science connections.

Martin and Ritz (2012) also identified four areas that they felt needed to be researched: teacher recruitment and retention, attracting and serving minorities, student organizations, and leadership within the profession. Additionally, they recommended a forum to discuss research activity to help develop priorities.

Theoretical Foundations

In the United States, technology and engineering education evolved from historical foundations in general education, apprenticeships, industrial practice, and training. For example, the practices of learning by doing and engaging the whole child in education is often attributed to the theories and work in the 18th - 20th centuries of Comenius, Pestalozzi, Froebel, and Dewey, among others (see Barella & Wright, 1981; Bennett, 1926 & 1937; Martin, 1979). Additionally, content and methods for curriculum, instruction, and laboratory design were refined by the manual training work in the late 1800's of Calvin Woodward at Washington University in Missouri and John Runkle at the Massachusetts Institute of Technology (Bennett, 1926 & 1937; Woodward, 1887).

In the early twentieth century, Charles Richards, Frederick Bonsor, and Lois Mossman, among others, advocated for the broadening of manual training to include the study of industry. The term industrial arts was embraced to have industry as the focal point and the arts would refer to the technical processes and aesthetics inherent in instruction. Through a majority of the twentieth century, however, William Warner, Delmar Olson, Paul DeVore, and others advocated for broadening the field's focus to technology, not merely industrial practice (Herschbach, 2009). In 1985, the American Industrial Arts Association (AIAA) changed its name to the International Technology Education Association (ITEA) to reflect this shifting focus. The Association would

change its name again in 2010 to the International Technology and Engineering Educators Association (ITEEA) to reflect the inclusion of engineering content and practices (Reed, 2017).

These theoretical foundations demonstrate how technology and engineering education is defined by content, epistemology, and a history of practice, inclusive of curriculum, teaching, and research (Reed, 2018). This study reviewed technology and engineering education graduate student research over the past twenty-five years (2000-2024) to better understand the content, epistemology, and practices that define the field and to see if graduate research is addressing published calls for research during that timeframe.

METHODOLOGY

This literature review was conducted by searching the 437 graduate studies identified by Rodriguez and Reed (2025) during a twenty-five-year period (2000-2024). Rodriguez and Reed (2025) conducted an integrative review using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines (Page et al., 2021). The researchers used Google Scholar, Publish or Perish software, and ProQuest to search for dissertations and theses using the following terms:

- Industrial Arts
- Industrial Education
- Industrial Technology
- Industrial Vocational Education
- K-12 engineering
- K12 STEM
- Makerspace
- Making and doing
- Manual Training
- Project Lead the Way (PLTW)
- STEM education
- Technology Education
- Trade and Industrial Education

The initial search yielded over 12,000 results that included journal articles, presentations, grey literature, theses, dissertations, and other publications. The researchers selected only the theses and dissertations, removed duplicates, and screened studies that fit within PreK-20 technology and engineering education using the definition outlined in *Standards for Technological and Engineering Literacy*:

> Technology and engineering education—The combined disciplinary study of the engineered (human-designed) world, the goal of which is to develop individuals with a breadth of knowledge and capabilities who see the interactions between technology,

engineering, and society and can use, create, and assess current and emerging technologies (ITEEA, 2020, p. 162).

The researcher in the current study used the Rodriguez and Reed (2025) database to search for the 17 most frequently presented and published research topics between 2006-2010, and 11 other topics, identified by Williams (2011). Williams analysed 472 research papers from four conferences and research manuscripts published in three journals from 2006-2010. Additionally, the topics on needed research identified by Lewis (1999), Cajas (2000), and Martin and Ritz (2012) were searched by the researcher in the current study to see if the graduate studies identified by Rodriguez and Reed (2025) address those issues.

RESULTS

The number of graduate papers from the initial search using topics identified by Williams (2011) is presented in Table 1. One limitation of this search is that the Rodriguez and Reed (2025) database only contains the study abstract and citation information (i.e., author, year, title, publication type, and publication location such as ProQuest or URL). Additional limitations of the Rodriguez and Reed (2025) database is the low number of master's theses and the low number if international studies. For the current study, theses and dissertations were only included in the count if their primary focus was on the topics identified by Williams (2011).

Table 1.
Number of Research Papers Identified by Williams (2011) and Number of Graduate Theses and Dissertations 2000-2024.

Topics (Williams, 2011)	No. of Papers and Articles (Williams, 2011)	No. of Graduate Studies
Design	42	31
Curriculum	34	36
Technological literacy	34	22
Thinking	32	21
Teaching	29	16
PATT	29	5
Teacher training	29	8
Learning	27	67
Values/beliefs	25	9
Sustainability/environment	22	3
Teachers' professional development	20	20
Creativity	18	7
STEM	18	49
Mobile/online delivery	16	7
Systems	15	2
Assessment	13	9
Classroom interaction	10	6

Williams (2011) predicted that the top four topics in Table 1 will continue to be researched based on interest and that science, technology, engineering, and mathematics (STEM) research will continue due to funding. These predictions certainly appear accurate when reviewing the consistency of dissertations and theses completed in the first four topics of Table 1. Additionally, graduate studies focused on STEM over the past 25 years constitute the second largest number of theses and dissertations using these topics. Teaching and learning are also topics that are well represented in the graduate student research.

Pedagogical Content Knowledge (PCK) and documenting the history of technology education were two predicted topics of research even though they were not on the list of paper topics identified by Williams (2011). History, PCK, and other topics he identified with fewer papers than those listed in Table 1 are included in Table 2 along with the number of theses and dissertations located in the database by Rodriguez and Reed (2025). Again, only the abstracts and citation information were searched for this study so topics with low numbers in Tables 1 and 2 are still likely being researched, they just may not be the main focus of graduate research.

Table 2.
Additional Topics Identified by Williams (2011) and Number of Graduate Theses and Dissertations 2000-2024.

Topics (Williams, 2011)	No. of Graduate Studies
Primary technology and engineering education	27
Innovation	21
History of technology and engineering education	10
Gender	9
Emotion	5
Information technology	4
Learning Styles	4
Electronics	3
Rationales for technology education	2
Pedagogical Content Knowledge (PCK)	2
Ethics	1

A third search of the Rodriguez and Reed (2025) database was made using the topics identified by Lewis (1999), Cajas (2000), and Martin and Ritz (2012). Many of the topics identified by these authors and listed in the literature review above are similar but their phrasing was different. For the current study, the researcher combined similar topics which resulted in 15 total topics to search. There were 303 theses and dissertations identified in this search and Table 3 lists the number of papers in each topic. It is important to note that there is redundancy of several topics across Tables 1-3 and the researcher included them in multiple tables since these topics have been repeatedly raised in the literature.

Table 3.
Topics Identified by Lewis (1999), Cajas (2000), and Martin and Ritz (2012) and Number of Graduate Theses and Dissertations 2000-2024.

Topics (Cajas, 2000; Lewis, 1999; Martin & Ritz, 2012).	No. of Graduate Studies
Benefit of K-12 technology and engineering education	83
Integration of technology and other subjects (e.g., STEM)	49
Curriculum & verification of content	36
Technological literacy	22
Cognitive science	21
Teacher professional development	20
Teaching & the work of technology teachers	16
Teacher Recruitment and Retention	10
Gender	9
Perceptions of technology	9
Leadership	8
Creativity	7
Attracting and serving minorities	6
Research	5
Student organizations	2

DISCUSSION

The purpose of this literature review was to see if graduate theses and dissertations produced between 2000-2024 were addressing published calls for research during that time. The short answer is yes, all the topics identified in the literature cited have been studied to varying degrees. However, this is a long period of time, so research shifts as political priorities change, new research emerges, and technology evolves.

An example of political shifts can be seen in the focus on STEM education during this period. Funding in the 1990s and early 2000s made this an area of increased student research. At the time of this paper, however, grant funding in the United States has been halted and even retracted in many areas so it is questionable whether STEM education research will continue to be a focus.

Research on curriculum, teaching, and teacher training has been consistent for decades (see Dyrenfurth and Householder, 1979; Householder and Suess, 1969; McCrory, 1987; Streichler, 1966; Zuga, 1994). These will likely continue to be focus areas in graduate research as these students are studying to better understand their classroom environments or are planning to use their advanced degrees to move into administration or teacher education.

There seems to be a focus on the area broadly categorized as *benefit of technology and engineering education*. This was one classification in the literature (see Table 3) and other topics identified such as learning, cognitive science, rationales for technology education, and thinking fit as well. These are all areas core to the epistemology of the field and should be continually investigated as research advances in education, psychology, technology, and engineering.

Caution should be exercised when reviewing graduate research and mentoring students. For example, there are still studies being conducted on learning styles despite the overwhelming research that demonstrates this is too general of a construct (see National Academies of Sciences, Engineering, and Medicine, 2018). There are numerous valid areas of research listed in the literature and many not identified in this study. I was surprised, for example that studies on laboratory/classroom environments was not discussed more given the proliferation of maker spaces, types of laboratories, commercial products, and informal learning environments.

Research itself is a persistent topic in the literature (e.g., topics, shortage of, methods). This study only identified five graduate studies focused on research which, in many ways, makes sense. For most graduate programs, the student thesis or dissertation is focused on the mentoring process, so questions/hypotheses and methods are limited and curated. Additionally, Foster (2010) noted that graduate students are using a variety of research methods so perhaps *research on research* is best left to post-graduate work or professional groups. It would be helpful for a group of professionals or a professional organization to outline a research agenda. *Tech Tally* (National Academies of Sciences, Engineering, and Medicine, 2018) is an example of such an effort that focused solely on technological literacy.

This study highlighted persistent calls for research and has shown that areas of needed research are being addressed. Tracking research remains important for a small field where program names vary and at a time when technology and engineering is being integrated into non-traditional areas (i.e., science, library maker spaces). The initial *Technology Education Graduate Research Database 1892-2000* (Reed, 2001) used seven search terms, but since the field has diversified so much in the past 25 years, 13 search terms were used to build the Rodriquez and Reed (2025) database. The goal is to post this resource on the CTETE website with the 1892-2000 TEGRD to aid researchers with longitudinal studies, meta-analysis, and other research.

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Green Hydrogen and AI: Shaping the Future of Fuel Cell–Super capacitor Systems for Sustainable Mobility

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Abstract

Green hydrogen, produced by water electrolysis powered by renewable sources such as solar and wind energy, is emerging as a key solution to today's energy and environmental challenges. It offers a clean, efficient way to decarbonize mobility and other sectors. This paper explores how green hydrogen, combined with fuel cell systems and supercapacitors, can be effectively integrated into engineering education to prepare students for the energy transition and the technologies shaping tomorrow's mobility.

We introduce the main principles of green hydrogen production and its role in powering fuel cell electric vehicles (FCEVs). The operation of fuel cells is discussed, with emphasis on how they convert hydrogen into electricity for zero-emission propulsion. In parallel, the role of supercapacitors is presented—they enhance system performance by delivering high power density and managing rapid load variations.

A major focus of the paper is the intelligent control and optimization of hybrid fuel cell–supercapacitor (FC–SC) systems using Artificial Intelligence (AI). Techniques such as adaptive control, machine learning, and predictive optimization are highlighted for their ability to improve energy efficiency, extend component life, and ensure smooth energy flow under varying driving conditions.

This pedagogical initiative is supported by a practical component: a hands-on experimental platform at the ASE-lab of ENSA Kénitra (Morocco), where students explore real FC–SC systems with AI-based control. The platform bridges theory and practice, reinforcing technical knowledge through experimentation.

The approach is designed for undergraduate students, combining theoretical insights with practical experience in renewable energy, hydrogen technologies, and intelligent control. Beyond technical training, it aims to raise awareness of sustainable development and empower future engineers to contribute meaningfully to a more inclusive and environmentally responsible future.

Key Words: Green Hydrogen, Fuel Cell Electric Vehicles (FCEVs), Supercapacitors, Artificial Intelligence in Energy Management, Sustainable Engineering Education

1. INTRODUCTION

The world is currently facing an environmental crisis, largely driven by climate change and intensified by human activities. This situation is mainly due to our excessive dependence on fossil fuels, such as oil, coal, and natural gas (Mayer, 2022). Although these resources have supported our industrial development for decades, their environmental and health costs are now immense (Lassioui et al., 2020). The combustion of these energies emits large quantities of CO_2 and atmospheric pollutants, contributing directly to global warming and the degradation of air quality in many parts of the world (Hamed et al., 2023). Faced with these challenges, alternative solutions are emerging, and among them, green hydrogen, which occupies a central place. Produced from renewable energies such as solar and wind power, it generates electricity without any emissions (Chen et al., 2019). Its use in fuel cells makes it a clean energy carrier, particularly suited to sustainable mobility. And by combining it with supercapacitors, we can design hybrid systems capable of responding effectively to power variations while improving component lifetimes (Rezk & Fathy, 2024).

These technologies, as promising as they are, require new skills. Therefore, it is important today to train engineers able to innovate in the field of clean energies, to learn how to use artificial intelligence to optimize energy systems (Fischer et al., 2020), and to understand the global challenges of sustainable development. The association of green hydrogen, fuel cell-supercapacitor (FC-SC) systems, and artificial intelligence plays an essential role in engineering education. This type of system provides a stimulating, practical learning experience for students, while also enabling them to familiarize themselves with the technologies involved in the energy transition (Kamel et al., 2021). Using teaching platforms that integrate these components, learners can explore current issues such as clean energy production, energy storage, and real-time optimization using AI. This framework encourages a multidisciplinary approach, combining energy, electronics, IT, and sustainability. It promotes learning about today's issues by tackling tomorrow's environmental, technical, and social challenges.

The present work deals with the educational integration of green hydrogen technologies. First, presenting the fundamental principles of green hydrogen production and its role in powering fuel cell electric vehicles (FCEVs). Then, the operation of FC-SC hybrid systems, focusing on the complementarity between the fuel cell and the supercapacitor for high-performance energy management. Also, the application of artificial intelligence in the control and optimization of these systems. In addition, we will describe the experimental platform developed at the ASE-lab of ENSA Kénitra (Morocco), its relevance to training, and the prospects it offers for forward-looking technological education.

2. GREEN HYDROGEN FOR MOBILITY

2.1. Definition and production process

Green hydrogen is hydrogen produced by water electrolysis, a process that uses electricity from renewable sources such as solar and wind power (Agaton et al., 2022). Unlike grey hydrogen, which is produced from fossil fuels and generates high levels of greenhouse gas emissions, green

hydrogen production is low-carbon, or even decarbonized. Its main aim is to contribute to the fight against global warming and aims to reduce dependence on fossil fuels, notably by replacing fossil hydrogen in industrial applications, while opening the way to new applications in economic sectors where decarbonization is more difficult (Koundi et al., 2023). At the current time, the most promising method for producing green hydrogen on an international scale is water electrolysis, due to its many advantages as shown in Figure 1. The process is based on the following chemical reaction:

$$2H_2O + \text{Electrical energy} \rightarrow 2H_2 + O_2 + \text{Heat} \quad (1)$$

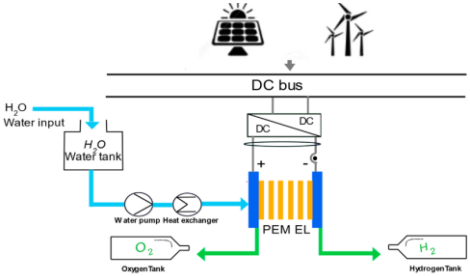

Figure 1:Green hydrogen production by PEM Electrolyzer

A number of technologies currently aim to electrolyze water to produce green hydrogen. Proton Exchange Membrane (PEM) technology is a recent development characterized by higher efficiency and a smaller carbon footprint. Its operation adapts better to different energy fluctuations and therefore to the intermittent nature of renewable energies, making it a highly attractive technology for green hydrogen production. A PEM electrolyzer (Figure 2) uses a polymer membrane that allows only hydrogen ions to pass through. Water is split into oxygen, hydrogen ions, and two electrons at the anode. The hydrogen ions and two electrons then pass through the membrane and are converted into hydrogen at the cathode (Falcão & Pinto, 2020).
A chemical reaction takes place at both the cathode and anode*:*

$$2H_2O \rightarrow 4H^+ + 4e^- + O_2 \quad (2)$$

$$4H^+ + 4e^- \rightarrow 2H_2 \quad (3)$$

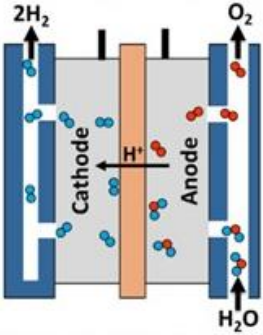

Figure 2: Schematic diagram of a PEM electrolyzer

2.2. Description of the experimental platform for green hydrogen production at the ASE-lab of ENSA Kénitra

To ensure the clean, sustainable production of green hydrogen, the energy source must come from a renewable source. In the ASE laboratory at ENSA Kénitra, solar energy is the main source used for this process. Using photovoltaic panels installed outside the laboratory (Figure 3), electricity is generated directly from the sun's rays. The panels are connected to a control unit located inside the laboratory, enabling precise control and supervision of the energy produced. This technological choice is part of an eco-responsible approach that promotes the laboratory's energy autonomy.

Figure 3: The photovoltaic panels used in green hydrogen production

Figure 4 shows the green hydrogen production process at the ASE-lab of ENSA Kénitra. The green energy generated by photovoltaic panels is first converted to alternating current by an inverter (DC-AC converter). The electrolyzer used in the laboratory is a Heliocentris hydrogen generator, specially designed to produce hydrogen. The demineralized water tank included in the system feeds the electrolyzer with the water required for production. The electrolyzer uses electricity to split the water molecules into oxygen and hydrogen. The hydrogen thus generated is then stored in tanks for eventual use in the hydrogen fuel cells also present in the laboratory. This installation platform illustrates a concrete and sustainable solution for the production of green hydrogen.

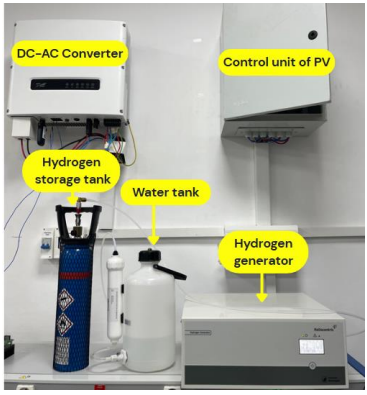

Figure 4: hydrogen production process at the laboratory

2.3. Green hydrogen for sustainable mobility

Green hydrogen as a contribution to sustainable mobility, capable of reducing environmental, Social, and economic impacts, air pollution, and, above all, improving air quality in cities, greenhouse gas emissions. Today, hydrogen fuel cell vehicles (HFCVs) offer long autonomy and very short recharging times, which make them highly suitable for long-distance and high-intensity use, as is the case for buses, trucks, or trains. Hydrogen, in addition to transport, has a strategic function as a renewable energy storage medium: It captures excess production and releases it when demand is high, it diversifies our energy sources, and strengthens the resilience of our infrastructures. That is the reason why it is crucial to integrate this technology into training programs to prepare tomorrow's engineers to meet these challenges with innovative solutions.

As shown in Figure 5, the complete process of green hydrogen, from production to end use, is presented. Once the hydrogen has been produced, it passes through advanced measurement techniques to guarantee its quality. It is then transferred to a filling center, where trailers are loaded for transport. The hydrogen is then destined for two main uses: industry and refueling stations for mobility. These stations supply hydrogen at 700 bar for cars and 350 bar for buses and trucks. Finally, mass flow calibration systems are installed at the distribution nozzles to ensure precise delivery. This global system reflects a clean, optimized supply chain to promote the integration of green hydrogen into the energy transition.

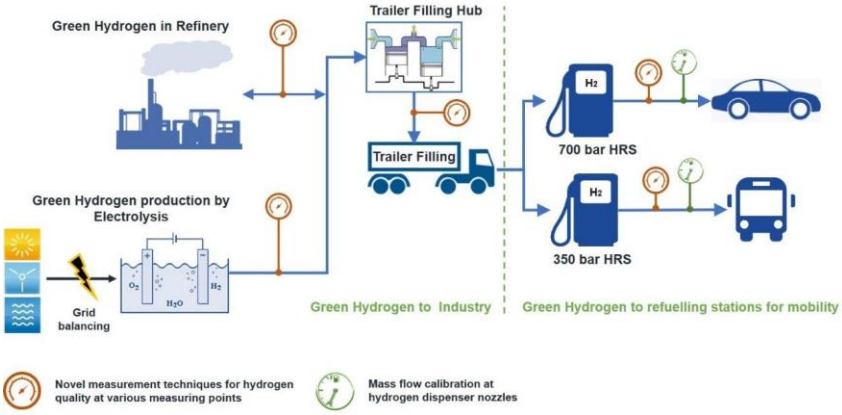

Figure 5: Green hydrogen mobility

3. FUEL CELL–SUPER CAPACITOR SYSTEMS

3.1. Principle of Hydrogen Fuel Cells (PEMFC)

A hydrogen fuel cell is an electrochemical device that converts the energy contained in hydrogen and oxygen into electrical energy. In the presence of a catalyst, hydrogen and oxygen are combined to create heat, water, and energy *(J. -S. Lai & M. W. Ellis, 2017)*. Several crucial components come together in a typical hydrogen fuel cell to generate energy. The PEM

electrolyzer technology shown in Figure 2 is similar to PEM fuel cell technology: Hydrogen gas is delivered to the anode and split into protons and electrons through a catalytic reaction. The cathode eases the reduction of oxygen, permitting it to combine with protons and electrons to form water, the primary byproduct. Between these electrodes stands the Proton-exchange membrane that lets protons move from the anode to the cathode while avoiding direct hydrogen and oxygen mixing (Belhaj et al., 2021).

3.2. Supercapacitors

Supercapacitors are a special type of electrochemical energy storage device with high specific capacitance and power density. In a comparatively short period, these systems can effectively release energy with a high density. It stores and releases energy by reversible desorption and adsorption of ions at the electrode-electrolyte interface (Libich et al., 2018). Supercapacitors are composed of two electrodes, an electrolyte, and a porous separator (Figure 6). This particular structure enables them to combine the characteristics of traditional capacitors and electrochemical batteries: supercapacitors store energy electrostatically, but they also use an electrochemical process to store and release energy (Banerjee et al., 2020).

Nanomaterial-based supercapacitors are used to increase the specific surface area of the electrodes, thereby enhancing the supercapacitor's performance. Increased surface area enables higher capacitance, which means the supercapacitor can store more energy while delivering improved performance. Materials such as graphene and carbon nanotubes are frequently used for this application, as they offer exceptional conductivity and a very large storage surface area, making them ideal for optimum performance (Farooq et al., 2024).

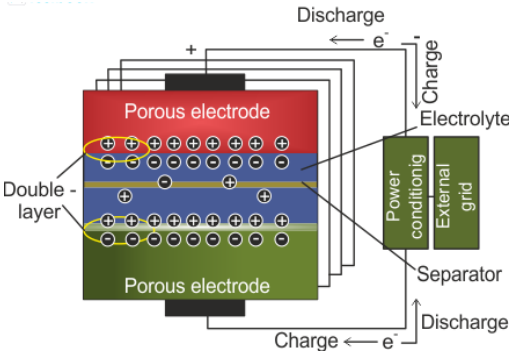

Figure 6: component of a supercapacitor

3.3. Architecture of Fuel Cell–Super Capacitor Systems

The architecture of a fuel cell-supercapacitor system for an electric vehicle combines a proton exchange membrane fuel cell (PEMFC) and supercapacitors, as shown in Figure 7. Its purpose is energy optimization and management in applications such as hydrogen electric vehicles (Rosas-Caro et al., 2021). It combines the continuous energy production of a fuel cell with the rapid response and short-term energy storage of supercapacitors (Sahri et al., 2021).

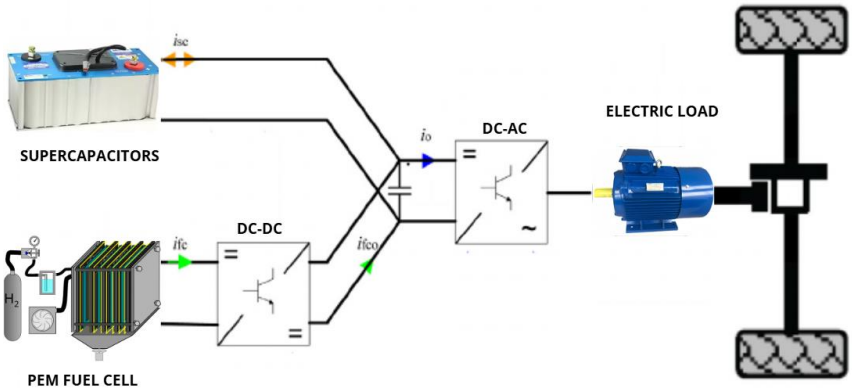

Figure 7: Architecture of Fuel Cell–Supercapacitor for electric vehicles

The operating principle of this architecture can be explained as follows: The fuel cell supplies direct current (DC) via a DC-DC converter, serving as the main energy source. At the same time, supercapacitors, also connected via a DC-DC converter, act as an auxiliary source, mainly for phases of high-energy demand or when recovering energy during braking. The role of the EMS (Energy Management System) as presented in Figure 8 is crucial in this architecture: it provides all information relating to the state of charge, power requirements, and operating conditions (Bayendang et al., 2021), and also controls the converters to intelligently distribute power between the sources. Finally, the DC-AC converter transforms the direct current from the Fuel Cell / Supercapacitor combination into alternating current to power the electric load (motor) (Zhao et al., 2024).

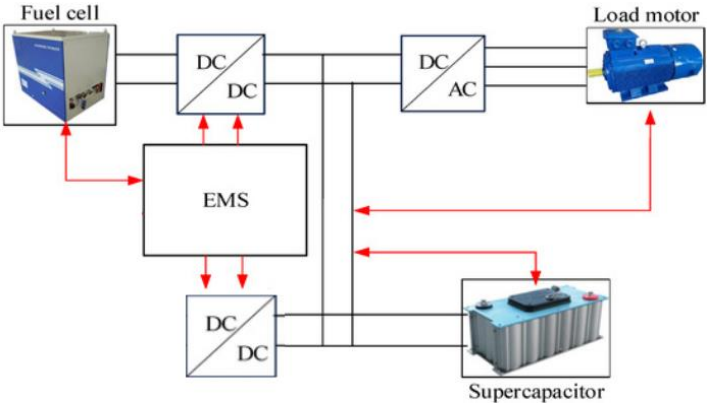

Figure 8: Schematic diagram of Fuel Cell–Supercapacitor with EMS systems

4. AI FOR INTELLIGENT MANAGEMENT OF FUEL CELL–SUPERCAPACITOR (FC–SC) SYSTEMS

4.1. Adaptive control technique

An adaptive control technique is based on the control system's ability to automatically adjust its parameters in response to changes in the controlled system's behavior. The aim is to maintain optimum performance in spite of parameter variations or unknown parameters (Annaswamy & Fradkov, 2021). Adaptive control follows three basic steps (Wang et al., 2021):

- Observation or estimation: where the controller measures system outputs and, sometimes, estimates certain unknown dynamic parameters
- Adaptation: based on measured errors between actual and desired output, the adaptation mechanism adjusts controller parameters in real time.
- Control: the newly adjusted parameters are used to calculate the optimum control to be applied to the system.

This process is iterative and continuous, enabling the controller to adapt to gradual or sudden changes in the environment, such as load variation, component drift, or model uncertainty. There are several adaptive control architectures, the most common of which are: Reference model adaptive control (RMAC), Self-adjusting controller (STR). Adaptive control enhances robustness, reduces energy losses, and improves component lifetime, making it an essential solution for real-time optimization of FC-SC systems in applications such as electric mobility or autonomous systems.

4.2. Machine learning

The application of machine learning to the intelligent management of fuel cell-supercapacitor (FC-SC) systems paves the way for advanced optimization of energy performance(Janiesch et al., 2021). In an FC-SC system, machine learning can predict energy demand, assess component status, or learn strategies for distributing energy between sources according to different driving or load profiles. Among the most commonly used approaches are artificial neural networks (ANNs), support vector machines (SVMs), as well as more recent techniques such as deep learning or reinforcement learning (Sharma et al., 2021).

These methods model the non-linear relationships between system inputs and the optimum power to be supplied by each source. Reinforcement learning, in particular, is particularly suited to learning energy management policies in a dynamic environment, maximizing a reward related to energy efficiency or system sustainability. By integrating machine learning, FC-SC systems become more intelligent, predictive, and autonomous, able not only to adapt to present conditions but also to anticipate future needs, making energy management more efficient, sustainable, and reliable (Cerezo et al., 2022).

5. INNOVATION IN ENGINEERING EDUCATION FOR A SUSTAINABLE FUTURE

5.1. Description of the experimental platform at the ASE-lab of ENSA Kénitra

The platform shown in Figure 9 is designed to test fuel cells and electric motors presented in many applications of mobility, such as hydrogen electric vehicles. This platform can be used to simulate and analyse real-world scenarios, such as those found in hydrogen fuel cell electric vehicles. The bench aims to optimize energy efficiency, component robustness, and stability, while ensuring the safety and reliability of the overall system. Key objectives include modelling motor and fuel cell dynamics, validating different control strategies, and collecting accurate data to refine models and improve overall system performance.

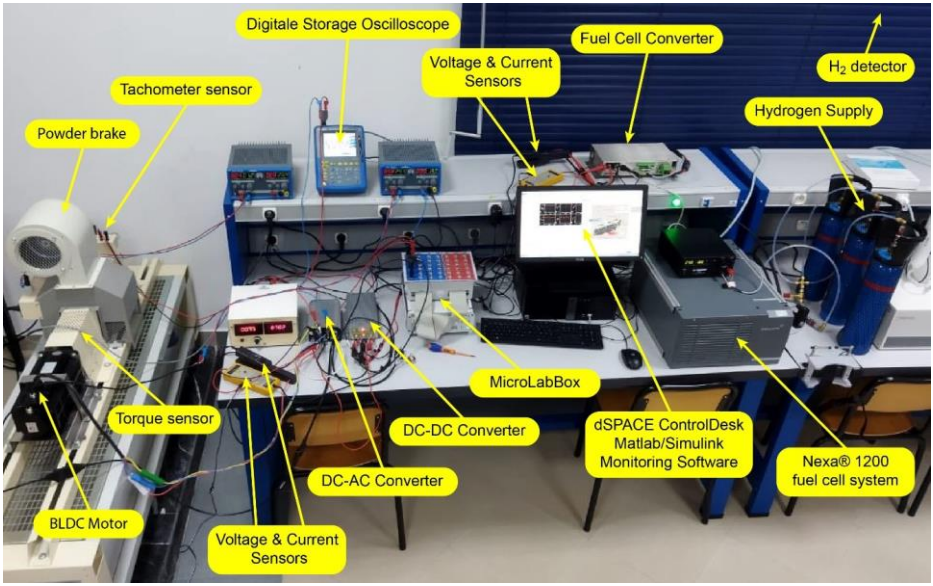

Figure 9:the experimental platform at the ASE-lab of ENSA Kénitra

The main components of the experimental platform and their role in the overall system are:

- BLDC motor (Brushless DC Motor): as a central element of the propulsion system, simulating the dynamic load to be supplied by the fuel cell. It is controlled in terms of speed and torque to test the fuel cell's response to different loads.
- Powder Brake: This is used to apply controlled loads to the motor, simulating real resistance conditions. It enables motor performance to be tested under different loads.
- Torque and Tachometer Sensors: to measure torque and speed, providing essential data for controller validation and for assessing the performance of the entire energy chain.
- DC-DC and DC-AC converters: to match voltages and currents between the fuel cell, motor, and other components. The DC-DC converter regulates the voltage supplied by the fuel cell, while the DC-AC converter adapts the power for the BLDC motor.
- MicroLabBox: A real-time data acquisition and calculation controller that executes control algorithms and collects experimental data. It acts as an interface between the test bench and the control and modelling software.

- Nexa® 1200 Fuel Cell System: This 1200 W fuel cell provides the main energy for the system. It supplies power to the motor and tests the cell's response in terms of power, stability, and durability.
- Hydrogen Detector (H_2 Detector): A safety feature that detects any hydrogen leakage from the stack, ensuring a safe environment for experimentation.
- CControl and Simulation Software (dSPACE ControlDesk and MATLAB/Simulink): These software packages enable modelling, real-time control, and monitoring of bench parameters. They provide an interface for controller adjustment, data acquisition, and post-processing analysis.

The experimental platform developed at the ASE laboratory of ENSA Kénitra brings important contributions to the test bench.

- Optimization of Energy Efficiency: through testing and enhancing the overall energy efficiency of the hydrogen fuel cell system, minimizing losses and maximizing component life.
- Study of Dynamic Response: Through rapid load variations, this test enables to analysis of how the fuel cell and motor react, facilitating the development of controllers for rapid, stable response.
- Robustness and Stability Control: the powder brake and sensors enable the simulation of disturbances and validate the robustness of the controllers, guaranteeing system stability under various conditions.
- Improving the durability of fuel cell systems: by studying their response to frequent load variations.
- Contribution to advances in sustainable mobility: by providing experimental data for the development of fuel cell-powered electric vehicles.

5.2. Pedagogical innovation for sustainable engineering education

5.2.1. Interdisciplinary Collaboration for a Comprehensive Approach

For technical sustainable solutions in hydrogen electric vehicles, considering social, cultural, and economic impacts is necessary. Integrating green hydrogen into society requires understanding human behavior, public policy, and energy access inequalities. In addition, engineers must understand the economic models behind hydrogen production and distribution, as well as the market implications of new technologies. By working with economists, engineering students can study financial aspects of green hydrogen projects (Vaverková et al., 2024).

Interdepartmental Collaborations should also take place in engineering education by working with peers from environmental science, social science, architecture, or political science departments. As well as Interdisciplinary Hackathons by programming events where students from different disciplines come together to solve common challenges, we also organise competitions to design a sustainable mobility solution using hydrogen technologies and AI to optimize energy networks.

5.2.2. Project-Based Learning for Sustainable Engineering

Project-based learning provides a dynamic and efficient approach to sustainable engineering education by immersing students in real-world challenges. The realisation of projects about green hydrogen and AI, energy storage systems, and intelligent energy management bridges the gap between theories and practice, encouraging learners to simulate, prototype, and optimize hybrid systems that meet the growing demands of sustainable mobility. Collaboration with industry enhances this experience by providing real datasets, technical mentorship, and exposure to current technological constraints and market needs. These projects can be aligned with the Sustainable Development Goals, offering meaningful impact assessments and encouraging participation in innovation competitions or public showcases. By engaging in such experiential learning, students become active contributors to the green energy transition, equipped to design intelligent and inclusive solutions for the mobility of tomorrow. Project-Based Learning in the context of green hydrogen, AI, and sustainable energy systems transforms students into active contributors to the energy transition. It promotes a mindset of innovation, interdisciplinary thinking, and social responsibility—preparing the next generation of engineers to lead the shift toward clean, intelligent, and inclusive mobility.

6. CONCLUSION

To conclude, the presented paper has explored the potential of integrating green hydrogen, fuel cell systems, supercapacitors, and artificial intelligence into engineering education. In addition to presenting the details of key principles of green hydrogen production and its crucial role in the decarbonization of mobility through fuel cell electric vehicles. The complementary function of supercapacitors in enhancing power response and system stability was also discussed. Furthermore, this paper presents also the significant contribution of AI-based control strategies in optimizing hybrid fuel cell–supercapacitor systems, with a focus on improving energy efficiency and system performance. The experimental platform ASE-lab (ENSA Kénitra) with its different components was presented, with the aim of applying theoretical knowledge in real-world scenarios for engineering students. The presented educational model not only strengthens technical competencies but also fosters a deep understanding of sustainable technologies. This initiative contributes to shaping a new generation of engineers who are capable of innovating responsibly and leading the shift toward a more sustainable and inclusive energy future.

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Mobilizing the Technology Design Process: An Analysis of Teachers' Practices in Quebec Secondary Schools

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Abstract

Replace the Technology Design Process (TDP) is a central element of the Quebec Education Program at the secondary level, valued for enabling students to explore abstract concepts through hands-on, concrete experiences. When effectively implemented, the TDP engages students in identifying a need, generating and evaluating design scenarios within given constraints, and planning the work required to develop a solution, with the teacher serving as a critical guide (El Fadil, 2016). Furthermore, despite its pedagogical potential, implementing the TDP poses significant challenges, as highlighted in previous research.

This study examines the implementation of the TDP in Quebec secondary classrooms through a didactic lens. Using a case study approach, the classroom practices of four teachers were analyzed as they engaged students in design tasks related to simple machines, a foundational component of mechanical engineering. The analysis focuses on four dimensions: (1) how teachers characterize the TDP, (2) Their rationale for using TDP in teaching, (3) Their instructional approaches and their practices related to TDP and (4) The challenges they report in implementing TDP. Findings provide insights into effective strategies for teaching the TDP and offer practical recommendations to support teachers in fostering student engagement, problem-solving abilities, and technical competencies through design-based learning.

Key Words: Technology design process, Teaching practices, Technology education, Simple machines

1. INTRODUCTION

Technology education as a school discipline plays a vital role in preparing students to navigate and shape an increasingly complex and technologically driven world. Far from being a peripheral subject, it encompasses a dynamic field of knowledge that is deeply embedded in everyday life through a vast array of artifacts, technical objects and systems (de Vries, 2018). Rooted in innovation, technology can be understood as a continuous process of designing, producing, and utilizing these artifacts (de Vries, 2007).

Among the core components of this discipline, the design process stands out as particularly significant. As de Vries (2007) emphasizes, design is the engine of technological creativity and innovation, generating new ideas that drive progress. In response to global challenges and the growing demand for technological literacy (ITEEA, 2020), it has become more essential than ever to equip students with foundational competencies in technology design (de Vries, 2018; Mawson, 2003).

Recognized as central to technology education (Ginestié, 2018; Kangas & Seitamaa-Hakkarainen, 2018; Pieper & Mentzer, 2013), design processes are now embedded in curricula across many educational systems worldwide (Brink et al., 2023). These processes involve the development and creation of technical objects (Norström, 2016), requiring not only creativity but also the application of conceptual and technical skills (Daugherty & Carter, 2018). Their pedagogical value lies in their capacity to foster deep learning. Through design, students learn to: (1) generate solutions using diverse approaches; (2) optimize outcomes based on needs and constraints; and (3) develop innovative products using various fabrication techniques (ITEEA, 2020).

The Quebec Education Program places strong emphasis on the Technology Design Process (TDP) as a central methodological approach within secondary-level Science and Technology (ST) education (Government of Quebec, 2004). As El Fadil (2016) points out, this process aligns closely with the first disciplinary competency: *"Seeking answers or solutions to scientific or technological problems."* This competency, which draws on logic, rigor, abstraction, and execution, aims to guide students toward improving technical solutions through structured inquiry and design (ATS Program: Government of Quebec, 2008).

Building on the central role of the TDP in the Quebec Education Program, it is important to recognize that teachers play a pivotal mediating role in facilitating students' engagement with technology design through their classroom practices (Brink et al., 2023; Daugherty, Carter & Swagerty, 2014; Laisney & Brandt-Pomares, 2015; Mawson, 2003). This pedagogical responsibility presupposes a solid understanding of the TDP; however, researchers such as Daugherty & Carter (2018) and El Fadil (2016) highlight the lack of consensus regarding the universality of design processes in technology education.

Indeed, the TDP is often viewed as a complex construct (Van Dooren et al., 2014), and the literature presents a variety of models that conceptualize it differently depending on the researchers' perspectives (Wells, 2016; Brink et al., 2023). This diversity can lead to inconsistencies in how teachers implement design-based learning (de Vries, 2007), potentially resulting in pedagogical drift and posing significant challenges when integrating design into technology education (Christensen et al., 2019; Dakers & Dow, 2009; Kelley & Wicklien, 2009).

Research Questions

Building on current debates in technology education, this study seeks to explore how the TDP is understood, enacted, and justified within secondary Science and Technology classrooms in Quebec. By examining teachers' perspectives and practices, the research aims to illuminate both the pedagogical intentions underlying the use of the TDP and the practical realities shaping its classroom implementation. More specifically, the study is guided by the following questions:

(i) How do secondary Science and Technology teachers in Quebec define the TDP within their teaching practices?

(ii) What pedagogical and educational purposes do teachers pursue when integrating the TDP into their classroom practices?

(iii) How do teachers integrate the TDP into their instructional practices, and what challenges or constraints do they face in its implementation?

2. CONCEPTUAL FRAMEWORK

2.1. The Technology Design Process

When designing a product or system to meet any human need of specific criteria, it is essential to rely on a structured set of procedures that lead to technological solutions aligned with those criteria, this constitutes the Technology Design Process (Wells, 2016). In this sense, the TDP can be viewed as an algorithm, or a logical sequence of steps aimed at solving a given technological problem in response to a need (Daugherty & Carter, 2018). According to Daugherty and Carter (2018), design typically addresses open-ended problems, where multiple technological solutions are possible. The selection of these solutions depends on a range of constraints, such as form, dimensions, and materials (Laisney & Brandt-Pomares, 2015). These observations highlight both the tangible and abstract dimensions of the TDP. The former refers to the ideas, strategies, and reasoning that guide the design process, whereas the latter refers to the tangible artifacts generated throughout the process, such as sketches, materials, and prototypes (Daugherty & Carter, 2018).

Several studies have proposed characterizations of the TDP (e.g., Childress & Maurizio, 2007; de Vries, 2016; Norström, 2016), leading to the development of models that generally fall into two categories: linear and non-linear (or cyclical) models (Norström, 2016). Linear models follow a clearly defined sequence of steps, beginning with a need and ending with a final product. However, these models have been widely criticized for being overly idealized and potentially leading to unrealistic design outcomes (Norström, 2016). In response to these limitations, non-linear or cyclical models have emerged as alternatives. These models are characterized by multiple iterations that allow for continuous improvement and optimization throughout the design process (Wells, 2016; Daugherty & Carter, 2018). Bucciarelli (1996, cited in Esjeholm & Bungum, 2018) argues that there is not a single TDP, but rather multiple processes that share common phases and activities (Norström, 2016).

According to El Fadil (2016), despite their diversity, TDPs generally involve three key stages: the formulation of a technological problem based on a need, the planning and implementation of the process, and finally, the development and conceptualization of a solution. Importantly, TDPs should be understood in their full complexity, not as a simple execution of sequential tasks (de Vries, 2007). In other words, they should be viewed as holistic processes that integrate both deliberate and spontaneous actions, with ongoing moments of reflection and exploration (Van Dooren et al., 2014).

2.2. Teaching Practice

Teaching practices can be understood as a system (Robert & Rogalski, 2002) in which the teacher's training, experience, and intentions shape their actions, decisions, and educational goals. These practices encompass a wide range of tasks that are too diverse to be exhaustively listed here (Lenoir, 2014). For the purposes of this framework, the focus is placed on classroom teaching practices, which are often mistakenly equated with overall teaching practice, despite being only one component.

Teaching practice, as defined by Altet (2001), includes not only direct interaction with students but also collaboration with colleagues, communication with parents, and partnerships with external actors. It involves a complex interplay of actions, reactions, interactions, and adjustments in response to professional situations. More specifically, teaching practice refers to a set of gestures and operational discourse embedded in the immediacy of the teaching-learning context (Altet, 2002; Bru & Talbot, 2001). Two key concepts are central to understanding teaching practices: situation and action. These require particular attention to grasp the logic behind instructional decisions (Bru, 2003; cited in Lefeuvre, 2005). Teaching practices are considered specific forms of social practice (Zaid et al., 2012), involving a series of actions carried out by the teacher in interaction with both content and learners. The teacher's role can thus be seen as a form of mediation in the process of objectification between the learner and the disciplinary content (Zaid et al., 2012). This mediation is twofold: didactic mediation, related to the content being taught, and pedagogical mediation, related to the strategies used to facilitate learning (Lenoir, 1996).

Given the complexity and multidimensional nature of teaching practice (Lenoir, 2014), research often distinguishes between observed practices and reported practices. Observed practices are based on classroom recordings and structured observation tools, while reported practices are derived from teachers' own accounts, typically collected through interviews or focus groups. In this study, the emphasis is placed on reported practices.

To analyze these practices in relation to the TDP and the research questions, we draw on the analytical framework proposed by Hasni (2011) and Lenoir (2014), which identifies four dimensions:

- The "What": This dimension concerns teaching practices with regard to teaching objectives, content, and approaches. In our study, this is the case for TDP.

- The "Why": This the dimension refers to the educational objectives of teaching and the learning outcomes targeted by the use of TDP.

- The "How": This is the dimension that deals with instructional approaches and the practices when mobilizing the TDP in teaching.

- The Organizational Dimension: Relates to the conditions and structures that shape the implementation of teaching practices.

3. METHODOLOGY

This qualitative case study aims to better understand how secondary school teachers in science and technology in Quebec perceive and integrate the TDP into their teaching. The study is based on an analysis of semi-structured interviews conducted during the preactive (pre) and postactive (post) phases of instruction. These interviews were recorded and fully transcribed.

The data comes from a research database compiled by the Centre for Research on Science Teaching and Learning (CREAS research Center). For this project, we first selected data that explicitly addressed the TDP. In the second phase, we focused exclusively on teaching situations involving simple machines. This content was chosen because it is a foundational component of the technological domain in Quebec's science and technology curriculum.

Based on these criteria, sequences from four teachers were selected for analysis. These teachers work in various secondary schools across Quebec. All of them teach science and technology at either the first or second cycle of secondary education and have varying levels of experience implementing the TDP. To protect the anonymity of the participating teachers, we assigned them the following codes: T1, T2, T3, and T4.

For data analysis, we categorized the teachers' statements according to four dimensions:

- How teachers characterize the TDP;
- Their rationale for using TDP in teaching;
- Their instructional approaches and their practices related to TDP;
- The challenges they report in implementing TDP;

4. RESULTS

In this section, we present the preliminary results of our study according to the four dimensions mentioned above.

4.1. Characterization of the TDP by the Teachers

Two teachers (T1 and T2) describe the TDP a linear sequence of clearly defined steps, followed in a specific order, from identifying a need to producing a final object. They emphasize that this process relies on a structured protocol that incorporates two key elements: innovation and problem-solving.

Teacher T1 explains the TDP as a process that begins with identifying a need; specifically, a need that requires the creation of an object. Students are then asked to design and build that object to

address the need. The teacher likens this to the work of a small engineering firm, where students act as designers tasked with developing an object to help someone accomplish a particular task. In essence, the process should be carried out in a kind of “professional” manner, following the same procedure a designer would use when creating a new product to meet a specific need.

Similarly, Teacher T2 emphasizes the importance of students developing their own protocol and designing a technical object to solve the problem. Students are also expected to create a proposal describing their design and to evaluate whether the final product meets the established criteria.

“This process [the TDP] is quite similar to the scientific method. We start with a problem, formulate hypotheses, which, in this case, are the students’ design plans, then move to experimentation, which corresponds to prototyping. After that, we reflect on what was done, which is like drawing conclusions, analyzing results, identifying errors, and noting possible improvements. They are essentially the same thing, but viewed through a technological lenses.”

4.2. Rationale for using the TDP in Teaching

The reasons for incorporating the TDP into science and technology classrooms vary among teachers. For example, Teacher T4 emphasizes the development of specific skills and competencies in students, stating:

"In terms of design itself, it’s about learning to use tools and materials, being able to form ideas, working in teams, and collaborating."

For Teacher T3, the primary goal of using the TDP is to familiarize students with the concept of design within a technological context while linking it to the content they are learning. He explains:

"I want my students to recall how technology design is experienced in real life, from identifying a need to prototyping, and to understand the concepts, ideas, and knowledge associated with each step."

4.3. Teaching Approaches Related to the TDP

Teachers’ statements indicate that they do not rely on a single strategy when implementing the TDP. Instead, they integrate four approaches: interdisciplinary, project-based, problem-based, and collaborative learning.

For example, Teacher T3 emphasizes a problem-based approach:

"The technology design process fits directly into a problem-based approach. You can’t teach it theoretically. If students are expected to design a technical object, that object must address a need and solve a real problem. Otherwise, what’s the point of creating something that doesn’t help people in a meaningful way?"

Teacher T1 highlights the natural emergence of interdisciplinary connections while still prioritizing problem-based learning:

"The interdisciplinary approach happened naturally; it wasn't my original intention. For example, students used mathematical knowledge, especially in geometry. It's a problem, it's a project. There's direct instruction, and a bit of everything, really. But the primary strategy is definitely problem-based learning: it's a problem you solve by designing an object."

4.4. Teaching Practices Related to the TDP

Building on the teaching approaches discussed in the previous section, our analysis identified three distinct categories of teaching practices:

i) Fully guided instruction: The teacher directs students through every step of the design process. Teacher T2 explained:

"I guided them step by step so they could better understand the outcome."

ii) Partially guided instruction: The teacher acts as both facilitator and observer. Teachers T4 and T1 described:

"After initial feedback, I supervise their choices, answer questions, and check whether their ideas are feasible. I move from team to team to support them," explained T4.

"My role is to guide them through the process, helping with choices like distances and sizes, while observing and supporting their construction," affirmed T1.

iii) Autonomous instruction: The teacher mainly observes while students take responsibility for the process. Teacher T3 stated:

"Students conduct a construction analysis, applying learned concepts and sketching on everyday objects to create the best-suited technical object. They encounter obstacles and revise their plans as needed."

Overall, these teaching practices reflect a continuum of guidance, highlighting how teachers in the Quebec context understand the TDP. The process can be adapted to support diverse student needs, foster varying degrees of autonomy and engagement, and ultimately promote deeper learning and problem-solving skills.

4.5. Challenges Reported by the Teachers

The implementation of the TDP by participating teachers was accompanied by several challenges. While some difficulties were related to organization and time management, during planning, preparation, or classroom execution, more significant obstacles arose from the inherently complex

nature of the TDP itself. Teachers identified gaps in their initial training, limitations in how the TDP is presented in textbooks, and students' prior educational experiences as key factors.

Specifically, teachers noted that university training and school textbooks did not adequately prepare them to teach the TDP. Unlike the scientific method or lab report procedures, which are more familiar and routinely taught, the TDP often felt unfamiliar and lacked clear instructional guidance, making classroom implementation particularly challenging.

Moreover, students' limited prior exposure to the TDP also posed difficulties. Accustomed primarily to scientific approaches, they struggled with the open-ended nature of technological design. This lack of experience made it challenging for students to develop solutions independently, relying only on general guidelines or criteria rather than direct answers.

Teachers further highlighted the insecurity students often experienced during the process. Since textbooks do not provide clear examples for carrying out the TDP, students had to rely on their own knowledge and judgment. Although a general method exists, constructing a technical object requires specific decisions, such as how to connect and assemble parts, which many students found particularly difficult.

5. DISCUSSION

The results reveal considerable variation in teachers' understandings of the TDP and its integration into classroom practices within the technological domain. This diversity aligns with prior research highlighting the complexity of design-based approaches and the absence of consensus regarding the universality of the TDP (e.g., Daugherty & Carter, 2018; El Fadil, 2016). While some teachers embrace the full complexity of the TDP, others conceptualize it as analogous to the scientific method or describe it merely as a sequence of steps, without fully considering the cognitive and functional dimensions that underlie the process—a point also emphasized by de Vries (2007).

Teachers' pedagogical intentions for using the TDP similarly vary, ranging from fostering specific skills and competencies to facilitating mastery of the process itself, while integrating diverse science and technology concepts. To achieve these goals, teachers employ multiple instructional approaches—project-based, problem-based, interdisciplinary, and collaborative—that they consider most appropriate for addressing students' needs within the TDP framework.

This spectrum of practices spans a continuum from fully guided instruction to the complete delegation of responsibility to students. As Ginestié (2018) observes, teaching through the TDP may follow a closed model, where the teacher directs students through each step, or an open model, in which students are presented with a technological problem without a predefined solution. The multiplicity of these approaches, reflecting broader diversity in pedagogical practices, is both significant and necessary, given the complex nature of the TDP and the challenges it presents within technology education.

These findings have important implications for teacher training and curriculum development. First, teacher education programs must provide both theoretical and practical preparation in the TDP, emphasizing its cognitive and functional dimensions, and equipping teachers to manage varying degrees of student autonomy. Second, school curricula and textbooks should include explicit examples and scaffolded guidance for the TDP, ensuring that students progressively develop the skills and mindset required for technological problem-solving. By addressing these areas, teacher preparation and curricular design can better support the effective implementation of the TDP, fostering deeper learning, creativity, and problem-solving competencies among students.

CONCLUSION

This case study provides a focused examination of the Technology Design Process in secondary science and technology education in Quebec. By analyzing teachers' understandings, pedagogical rationales, instructional approaches, and reported challenges, the study offers a nuanced perspective on the current implementation of the TDP and contributes to the limited research in this area.

Although the findings are specific to the studied context and sample, they carry broader implications. They highlight the need for enhanced teacher training, more explicit curricular guidance, and classroom strategies that support students' engagement with the TDP. These insights can inform policy decisions, curriculum development, and professional development programs, while also guiding future research aimed at improving technology design education.

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Complexity as a way to meet the needs of gifted students: A framework for analysis of technology education activities

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Abstract

In technology education, gifted students need complexity but few studies address this phenomenon. Differentiated instruction and educational activities that provide complexity can meet diverse learning needs and create inclusive settings. In Sweden generally, inclusive settings are common. The aim of this paper is to present a framework for analyzing complexity in technology education activities. The framework combines knowledge dimensions (factual, conceptual, procedural and metacognitive knowledge) with abilities (remember, understand, apply, analyze, evaluate, and create) and higher order thinking. An exemplar activity for lower secondary technology education will be used to demonstrate the utility of the framework as an analytical tool. The results can provide input in planning and developing technology education concerning gifted students' needs of complexity and contributes to a discussion about inclusiveness in the settings of technology education.

Keywords: gifted students, complexity, technology education activities, gifted education, framework

1. INTRODUCTION

Technology education in Sweden aims at developing knowledge *in* and *about* technology for all students. Complexity is important in technology education to create differentiated instruction and meet gifted students' needs. Within an inclusive setting, differentiation is crucial. For gifted students who need complexity (VanTassel-Baska & Stambaugh, 2005) it is of importance that complexity is offered in all subjects, including technology education (Brink, 2025). However, there is a lack of studies describing what constitutes complexity in relation to technology education activities, which is needed to be able to critically examine and discuss challenges for students all students, included gifted students. Further, the Swedish school inspectorate (2014, 2019) states that technology education can differ from the intentions in the curriculum, and that the same content can be taught at different occasions without adequate progression. As a result, students can lack challenges and opportunities for learning.

Activities in technology education need to provide students with complexity and to be designed to further the aim of the technology subject. Hence, activities need to be systematically analyzed

to find out how complexity can be offered. Using a framework for analyzing activities, the *what* and *how* aspects of education can be examined and various knowledge dimensions and abilities can be made explicit. The following research questions guide this work:

- How can technology education activities be described?

- How can complexity in technology education activities be analyzed?

2. TECHNOLOGY EDUCATION IN SWEDEN

The school subject technology differs between different educational systems. In Sweden, the subject stems from traditions of crafts and engineering, and from knowledge about the technology surrounding us in daily life. Hence, technology education consists of different types of knowledge, abilities, competences, skills and processes (Elgström & Riis, 1990; Hallström et al., 2013; Hallström & Klasander, 2013; McCormick, 1997; Nordlöf, 2022; SNAE, 2022). These traditions and types of knowledge intertwined give the technology subject its character and enable students to learn *in* and *about* technology.

Technology teachers in Sweden are free to make educational decisions based on individual interpretations of the curriculum. As a result of that, both content and teaching methods can differ between schools and also within the same school (Swedish school inspectorate, 2014, 2019). The teachers' own understandings of the characteristics of the technology subject are important when designing technology education and making decisions about content (Fahrman, 2021). Technology education content can be divided into technology from a civic point of view, and technology from the view of an engineer (Nordlöf, 2022). Another content division is the one between digital and analogue technology in relation to technological solutions (Hallström, 2022). Further, students are expected to develop and create technical solutions to technical problems and reflect upon the solutions. Often different stakeholders have conflicting interests, causing dilemmas for students when reflecting on different solutions. This type of conflict between several possible solutions is yet another characteristic of technology education, as is the use of authentic problems (Hallström & Schönborn, 2019). Careful design of relevant activities in technology education, combining different traditions and characteristics and offering complexity to gifted students (and to all students), is important. When students engage in well-organized activities, they can develop different knowledge dimensions and, in addition, abilities can contribute to enhanced technical skills (Niiranen, 2021).

3. THEORETICAL BACKGROUND

Various taxonomies can be used for analyzing learning, yet they lack descriptive aspects of complexity focused on the students' own activities. Aspects of complexity are important when analyzing activities as a way of creating challenging and stimulating education. Therefore, a framework for analyzing complexity in technology education activities has been developed, based on 1) indended learning objectives, 2) a taxonomy for learning and 3) higher order thinking.

3.1 Intended learning objectives

Learning is always about something and learning cannot take place without a content to be learned (Marton, 2015). The teacher designs learning activities based on the selected content, and the result of that design is referred to as the intended learning objective (ILO) by Brink et al. (2022). Researchers show that ILO encompasses both a direct content (the *what* aspect of teaching) and an indirect content (the *how* aspect of teaching) (Marton & Booth, 1997; Marton & Tsui, 2004; Lo, 2012). Direct content refers to knowledge in different dimensions whereas indirect content refers to what the students should learn to *do* with the direct content. Indirect content thus includes various abilities. Figure 1 shows that ILO consists of both direct content (what) and indirect content (how), and that ILO should aim to develop knowledge and skills through using abilities.

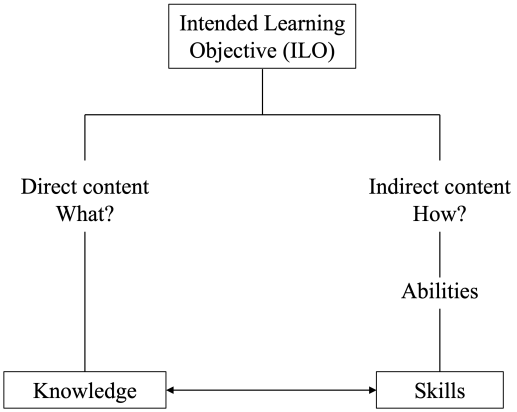

Figure 1. Intended Learning Objective (ILO), encompasses both direct content and indirect content which can be developed into knowledge and skills through the use of abilities.

When using abilities in a technical activity, the abilities can develop into more specific technical skills. Knowledge and skills relate each to other through the technical context, and also in the sense that skills can be manifested as knowledge (SOU 1992:94). When teaching, a teacher should focus on both parts of ILO (direct and indirect content) according to Marton and Tsui (2004). The dual focus correlates with the aim of the technology subject in Sweden, which is to develop students' abilities so that they can do something with a technical content (SNAE, 2022). ILOs are enacted in teaching through activities, and activities can be described taxonomically.

3.2 Taxonomy for learning

When activities in technology education are to be described, both direct and indirect content must be included. Anderson and Krathwohl (2001) revised Bloom's taxonomy with respect to what a student should do with a content in a way which aligns with the aim of this study. The revised taxonomy comprises four knowledge dimensions (factual, conceptual, procedural, and

metacognitive knowledge) and six abilities (remember, understand, apply, analyze, evalutate, and create) organized in a matrix (see Table 1).

3.2.1 Knowledge dimension – what can be learned?

The basic idea of Swedish technology education, that students should develop knowledge *in* and *about* technology, results in different dimensions of knowledge. Anderson and Krathwohl (2001) presents four knowledge dimensions relevant for technology education that can be applicable in school contexts: factual, conceptual, procedural and metacognitive knowledge.

Factual knowledge concerns the basic elements of a discipline that students should know in order to be familiar with and solve discipline-specific problems. Factual knowledge can refer to for instance terminology or solitary components, for instance names and profiles of various beams for stable structures, or different commands for programming as for-loop and if-than-else statement. *Conceptual knowledge* focuses on the relations between the basic elements and how the elements can function together in technological systems. Students can learn the principles of a sink trap or a trapway, or they can learn to categorize and classify different elements. *Procedural knowledge* refers to methods, techniques and procedures of how to do something, and students can learn to assemble parts or to work in project groups. Anderson and Krathwohl (2001) and McCormick (1997) also states that procedural knowledge involves criteria for determining when to use a specific method or procedure. The fourth knowledge dimension, *metacognitive knowledge*, is described as thinking about and reflecting upon one's own knowledge (Anderson & Krathwohl, 2001; Kuhn, 2021; Schunk, 2020) and students can take a position on any issue based on experiences or previous knowledge, or develop understandings on the grounds on which these experiences and previous knowledge are based.

3.2.2 Abilities – how can students learn?

One point of departure in this study is that students use their *abilities* when doing something in technology education activities. These abilities need to be defined in order to analyze activities and to understand how abilities can develop into more specific technical skills. The abilities adopted in this study (Anderson & Krathwohl, 2001), aligns with abilities used in the syllabus for the technology subject (SNAE, 2022). The ability *remember* means that students retrieve information from memory or that information is given in the activity that students recall. Within the ability *understand*, students can interpret, summarize, compare or explain technological solutions or components. They can use information in a context while making meaning, for instance explain technical concepts and describe when and how different tools can be used and when to prefer various components. *Apply* is an ability where students execute and implement procedures in a given situation. This ability is described in similar ways by several researchers (c. f. McCormick, 1997). Students can do something with or without tools, and the tools can be digital as when making digital code while programming, or analogue, as in using a screw driver to screw.

Further, the ability *analyze* is described by Anderson and Krathwohl (2001) as breaking down a technological solution or system into its constituent parts to find out how the parts relate to each other and to an overall structure. The parts can then be organized or differentiated by the students. The solutions, systems or structures analyzed can be concrete or abstract. *Evaluate* means that the students relate something to value or function (or both), often based on given criteria. For

example, students can evaluate a product for a certain group of people, such as children or the elderly. *Create*, finally, is described as an ability used when constructing artefacts, products, or systems and where creativity combining previous experiences and knowledge, is important.

The six abilities can be understood as partially hierarchical and growing in complexity according to Anderson and Krathwohl (2001) and Krathwohl (2002), in the sense that *understand* is more complex than *remember*, and *create* more complex than *evaluate.* Some of the presented abilities are prerequisites for other more complex abilities, and Newman et al. (1998) explain that basic knowledge and skills are needed to solve problems and more advanced knowledge and specialized skills are needed to solve more complex problems. Some overlap exists, however, in the hierarchy. For instance, explain as part of the ability understand can be seen as more complex than execute as part of the ability apply.

To conclude, the knowledge dimensions and abilities described in the revised taxonomy (Anderson & Krathwohl, 2001) give opportunities to analyze activities based on *what* to learn and *how* to learn, but still, aspects of complexity are absent for a systematic analysis. Therefore, *higher order thinking* is added the revised taxonomy.

3.3 Higher order thinking – complexity in technology education activities

Higher order thinking can be differently defined in various contexts (Lo & Feng, 2020; Schraw et al., 2011). In this study, Lipmans (2003) definition of higher order thinking will be used, as it aligns with gifted students' needs of complexity in technology education, described by Brink (2025). Lipman defines higher order thinking as critical thinking, creative thinking, and complex thinking, separately or interacting. Critical thinking includes logical reasoning and reflecting upon ideas, actions, and arguments. Other researchers describe critical thinking likewise (Schunk, 2020). In this study critical thinking will be interpreted as related to the categories *analyze*, *evaluate,* and *metacognitive knowledge*. Creative thinking involves combining previous experiences and knowledge in new ways to find possible solutions to technical problems (Lipman, 2003). Creative ideas can be seen as innovative solutions and, in this study, creative thinking is interpreted as related to the ability *create*. Schunk (2020) writes that creative thinking is developable and that more creative actions are possible with more specific knowledge in an area.

Complex thinking, finally, is focused on solving problems, with respect to content and context (Lipman, 2003). Problem solving is part of product development processes in a school context (Citrohn et al., 2023), and complex thinking is therefore interpreted as related to the abilities *understand*, *analyze*, *evaluate* and *create* in this study. According to Schraw et al. (2011), complex thinking involves aspects of reasoning, argumentation, critical problem solving, and metacognitive thinking. They write further that some activities can be so complex that all aspects of complex thinking need to be used simultaneously. Schunk (2020), on the other hand, explains complex thinking as metacognition, concept knowledge, problem solving and critical thinking, reasoning and creativity. So, complex thinking is also interpreted as *conceptual-*, *procedural-*, and *metacognitive knowledge*. As a result, complex thinking consists of both knowledge and abilities.

4. SYNTHESIS OF KNOWLEDGE DIMENSIONS, ABILITIES AND HIGHER ORDER THINKING

A combination of the four knowledge dimensions, and the six abilities can be visualized in a matrix (Table 1). Synthesizing higher order thinking to the matrix, a framework for analyzing complexity in technology education activities (AKTA[1]) is established which can be used to answer the research questions of this study.

Table 1. Framework for analyzing complexity in technology education activities.

		Abilities					
		Remember	Understand	Apply	Analyze	Evaluate	Create
Knowledge dimensions	Factual knowledge						
	Conceptual knowledge						
	Procedural knowledge						
	Metacognitive knowledge						

The result of the synthesis are shown with grey cells in Table 1. Studying the grey cells, combinations of knowledge dimensions: conceptual, procedural, and metacognitive knowledge, and abilities: understand, analyze, evaluate, and create, constitutes complexity in activities. As an example, if an activity requests the students to evaluate a procedure in terms of pros and cons, the activity should be understood as complex, since both the ability analyze and the ability evaluate as well as procedural knowledge are involved in the activity and both critical and complex thinking is required in order to break down the procedure in its constituent parts. Using AKTA, an activity can be marked in one or in several cells, and the grey cells show complexity. Further, AKTA is meant to be used for the knowledge dimensions and abilities that the specific activity aims to develop. Some knowledge and abilities are prerequisites for certain activities; however, they are not in focus when analyzing with AKTA.

[1] AKTA is an abbreviation from Swedish, Analysis of Complexity in Technology education Activities (Analys av Komplexitet i Teknikundervisningens Aktiviteter)

5. DESCRIBE, ANALYZE AND DEVELOP TECHNOLOGY EDUCATION ACTIVITIES

In this section, an exemplar technology education activity, representative of lower secondary education (students age 13–15), is presented and analyzed with AKTA. In addition, a suggestion is made to increase the complexity of the activity.

The exemplar is an activity from a technology textbook where the students are asked to answer the question: *Which views are included in a technical drawing?* (Frid & Hendersson, 2023). In the textbook there is an associated section with information about technical drawings and students can recall and repeat that information. When using AKTA for analysis, *factual knowledge* and *remember* are marked (Table 2). The activity, as presented in the textbook, is thereby not a complex activity as higher order thinking is absent (Lipman, 2003). To make the activity complex, the question can be reframed: *Why are only three views usually sufficient in a technical drawing?* This change means that students need to demonstrate their understanding of the concepts view and technical drawing in order to explain them, and higher order thinking will be involved. Consequently, *conceptual knowledge* and *understand* are marked in AKTA (Table 2).

Table 2. A non-complex activity, and a complex activity (bold) analyzed with AKTA.

Knowledge dimensions	Abilities: Remember	Understand	Apply	Analyze	Evaluate	Create
Factual knowledge	Which views are included in a technical drawing?					
Conceptual knowledge		**Why are only three views usually sufficient in a technical drawing?**				
Procedural knowledge						
Metacognitive knowledge						

6. DISCUSSION AND IMPLICATIONS

Until now, a framework for analyzing technology education activities with respect to complexity has been missing. AKTA can fill this gap. A focus on knowledge dimensions and abilities (Anderson & Krathwohl, 2001) enables identification of higher order thinking, as conceptualized by Lipman (2003). Moreover, the absence of higher order thinking can also be observed in the activities. The activity can then be adjusted to create more combinations of knowledge dimensions and abilities, to meet students' needs of complexity.

AKTA provides a means to distinguish knowledge dimensions from abilities. It emphasizes how education can be enacted to develop abilities into technological skills and to enhance technological knowledge in different dimensions. Furthermore, AKTA can support the implementation of differentiated instructions, tailored to diverse needs. When designing teaching, it is important to focus on both direct and indirect content, according to Marton and Tsui (2004), and Marton (2015) also argues that this dual focus should be in interaction with each other. AKTA provides a framework for this, while also paying equality attention to direct and indirect content. That is consistent with the character of the Swedish technology subject, where students should learn *in* technology and *about* technology (SNAE, 2022).

In a recent study, Brink (2025) found that gifted students need complexity in technology education. The capacity of AKTA to detect complexity in activities can pro-actively help teachers focus on all students in need of complexity. Thus, technology education activities need to be examined critically and discussed to meet these needs. An additional reason why technology education activities need to be analyzed with regards to complexity is that reports from the Swedish school inspectorate (2014, 2019) states that technology education deviates from the intentions of the curriculum in a number of schools. Education can in some schools be too simple and there is a risk that students are taught the same content more than once without meaningful progression.

To sum up, AKTA can be used in technology education research to compare, examine, and develop activities and teaching. Since technology education curricula varies in different educational systems, a well-defined framework such as AKTA can contribute to improve the technology subject.

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Displays of understanding and skills in technical vocational education

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Abstract

There is a lack of research studies in the field of technical vocational education exploring teaching and learning processes, especially regarding practice-based research studies focusing practical objects of learning (Carlgren et al., 2015; Kilbrink et al., 2022). Furthermore, studies on vocational education in Sweden have shown that students in vocational education have diverse backgrounds with, for example, a high proportion of immigrants (Andersson, 2019) and students with incomplete or low grades from compulsory school (Korp et al., 2025). The lack of a solid foundation of research on teaching and learning in the field entails teachers not having sufficient access to a research base to plan, carry out and evaluate their teaching. From an equity, diversity and inclusion point of view this is problematic and teaching methods including more aspects than verbal communication need to be elaborated on.

This paper will focus on students' embodied and verbalized displays of understanding and skills regarding practical objects of learning in technical vocational education. Transcribed excerpts of video-filmed teaching sessions in welding and building/ construction education will be presented and analyzed in the paper. The results show how the teachers with the support of the pedagogic approach CAVTA (Conversation Analysis and Variation Theory Approach) encourage students to display their embodied understanding and skills in multimodal ways, thus enabling for the teacher to adapt the progression of the teaching according to students' displayed understanding and skills. Our study has implications for teaching and learning of practical objects of learning in technical vocational education and is a contribution to broaden the base of educational research in the field.

Key Words: CAVTA, vocational education, learning study, TVET, practical objects of learning.

1. INTRODUCTION

33 % of the students registered at national programs of Swedish upper secondary schools attend vocational programs (Skolverket, 2024). Nevertheless, research studies exploring teaching and learning processes in the workshops of technical vocational education are scarce (Kilbrink et al., 2022). The Swedish Education Act (SFS 2010: 800) states that all education should be based on scientific evidence, but vocational teachers have to rely on general learning theories and educational research which may, or may not, be relevant to their practice. The fact that students in vocational education have diverse backgrounds with, for example, a high proportion of immigrants (Andersson, 2019) and students with incomplete or low grades from compulsory school (Korp et al., 2025) adds further motivation for the call of more research in this field. Vocational teachers ought to have access to a solid foundation of research focusing their programs, so they can form qualitative teaching from their perspectives – not the least from an equity, diversity and inclusion point of view.

This paper will focus on teaching and learning processes in the workshops of building/ construction and welding education. Video-filmed and transcribed sequences will be presented and analyzed in the paper. With the support of the pedagogic approach CAVTA (Conversation Analysis and Variation Theory Approach), the teachers plan, enact and evaluate teaching sessions with focused practical objects of learning where visualization of specific critical aspects of the object of learning along with the ambition to let the students display their understanding and skills are key elements. The teachers' visualizations and the students' displays of their understanding and skills are multimodal – verbalized as well as embodied. The students' displays are encouraged by the teachers and they enable for the teacher to adapt the progression of the teaching according to the students' capacities. Our study has implications for teaching and learning of practical objects of learning in technical vocational education and is a contribution to broaden the base of educational research in the field.

2. LITERATURE REVIEW

Although the studies exploring teaching and learning processes in the workshops of technical vocational education are scarce (Kilbrink et al., 2022), research focusing embodied behavior of diverse activities is extensive – especially within the conversation analytic tradition (Gardner, 2019). The use of video recorded data combined with a conversation analytic multimodal approach studying interaction, verbalized as well as embodied, has proven fruitful (Goodwin, 1994; Melander Bowden, 2019), although doubts have been raised about the use of conversation analysis in studies focusing learning processes (Gardner, 2019). Indeed, the question if the emic perspective of conversation analysis can be used to make claims about what seems to be hidden within our brains is relevant. Nevertheless, conversation analytic researchers have continued developing various approaches of studying learning situations over the last decade and they have contributed to the field of educational research ever since the seminal study presenting the social organization of interaction in school institutions, in the form of the initiation-reply-evaluation sequence (Mehan, 1979).

Video recordings bring the advantage of studying bodily conduct and multimodality along with the speech in an interaction (Goodwin, 2007; Heath et al., 2010; Mondada, 2018) and the

analytic process entails the possibility of scrutinizing the video-recorded sequences repeatedly and with opportunities of slowing events down and enlarging specific phenomena (Derry et al., 2010). Thus, researchers in the field of education and learning have found the development of the video technology profoundly useful (Derry et al., 2010; Gardner, 2019), and in the field of technical vocational education its use have contributed to results highlighting how artefacts can be used in the interaction in the midst of learning situations which include authentic enactments of practical activities (Asplund et al., 2022; Axelsson, 2023; Filliettaz, 2011).

3. METHODOLOGY

The theoretical point of departure of this paper is the systematic combination of conversation analysis and variation theory. Emanuelsson and Sahlström (2008) inspired Asplund and Kilbrink (2018) to develop and use the combination of conversation analysis and variation theory in workshop studies of technical vocational education. The results spurred them on (Asplund & Kilbrink, 2020; Kilbrink & Asplund, 2020) to merge the two perspectives into a pedagogic approach, Conversation Analysis and Variation Theory Approach (CAVTA).

The idea of CAVTA is to make use of a combination of conversation analysis and variation theory systematically, and relevant information of respective perspective is presented in this section of the text. CA captures how participants negotiate meaning in interaction (Sidnell & Stivers, 2013). Progress in video technology have made teaching and learning situations at school accessible and to meet the demands, the CA tradition have developed a conceptual apparatus and new transcription standards to describe multimodality (Mondada, 2018). The CA perspective in CAVTA also entails ample interaction in the teaching sessions, with the teacher encouraging the students to express their understanding of the object of learning in dialogue with the teacher. Moreover, this dialogue need not be verbalized – the complete contextual configuration (Goodwin, 2000) is to be taken into account. Planning and enactment ought to utilize all the semiotic resources at hand in the teaching sessions.

Variation theory (Marton, 2015) focuses the learning content in a learning situation. The concept object of learning (OoL) is central and a nuanced discourse has been developed to define the concept. In this paper a simplified description will suffice: In a teaching and learning situation, the planned OoL is the specific contents the teacher plans to address, the enacted OoL is what is possible to learn in a teaching situation and the lived OoL is the students' understanding of the OoL. In a teaching situation the teacher should move from entities to specific aspects of the OoL and support the students' discernment of the aspects. The aspects a student needs to discern in order to progress are called critical aspects and one powerful way of helping the student discerning them, is by designing a pattern of variation called contrast (Lo, 2012). The variation theoretic perspective in CAVTA includes the planning, enactment and evaluation of a teaching and learning situation with a limited OoL where few expected critical aspects are focused in the teaching session.

The data of this paper has been collected from two research projects funded by the Swedish Institute for Educational Research: *Learning to weld in vocational education* (ref no 2017-00056) and *Approaches to subject-specific teaching for increasing opportunities for learning in vocational education* (ref no 2022-00035). They have been designed with inspiration from the

learning study model (Carlgren et al., 2017) – a model consisting of iterative cycles of planned, enacted and evaluated teaching sessions. We have chosen not to describe the different stages of the learning studies further, since they are not relevant to the focus of this paper. However, contextual details of the teaching and learning situations will be presented alongside the selected examples.

The transcriptions of the video-filmed sequences below are inspired by Jefferson (2004) and Mondada (2018), although we have adapted the conventions to enhance the readability. In the transcription process, we have made decisions what to highlight. Such an approach may guide the reader to see points developed in the study (Goodwin, 1994). The analysis has focused on the teachers' and students' embodied and verbalized interaction and the selection of the sequences have been carried out accordingly. The analysis draws upon conversation analytic and variation theoretic traditions, using their concepts.

Ethical considerations have been made in the projects and we have adhered to the recommendations made by the Swedish Research Council (Vetenskapsrådet, 2002; 2017)

4. RESULTS

4.1. An example from the building and construction workshop

The first example is from a building and construction workshop. Two pairs of students have been given the task of lifting a window into its right place in a house wall, and doing it in the most ergonomically advantageous way possible. In the example, the teacher instructs how to lift and insert the window as smoothly as possible. One of the students, referred to as student 1 in the example, has lifted the window in a way that the teacher has noticed as a less advantageous way, which is why the teacher again instructs the student how the window should be handled during the lift. Preceding the example, the teacher has performed an instructing lift of the window together with student 2. He then turns to student 1.

Example 1

1	T:	var du med?
		did you follow?
2	S1:	ja
		yes
		((teacher and student 2 place the window on the floor again. Student 1 stands up))
3	T:	[s-st- så du måste ha lite mer kropp bakom liksom än (.)
		int- inte så
		[s-st- so you have to put a little bit more body behind like (.)
		not- not like that
4	t:	[((moves in relation to the window))
	fig:	[figure 1
5	S1:	nej
		no
6	T:	[och inte så
		[and not like that
7	t:	[((moves in relation to the window))
	fig:	[figure 2
8	S1:	nej
		no
9	T:	[utan lite (.) nästan förtifem grader om man säger så
		[but a little bit (.) almost forty five degrees so to speak (.) so
10	t:	[((moves in relation to the window))
	fig:	[figure 3
11	S1:	mm
		mm
12	T:	från (.) härifrån
		from (.) here
13	S:	mm (.) å herregud (.) ja
		mm (.) oh my god (.) yes
14	s1:	[((grabs the window squats in a new position))
	fig:	[figure 4

Figure 1

Figure 2

Figure 3

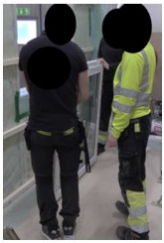

Figure 4

After the teacher (together with student 2) has lifted the window and thus modelled for student 1 how the window should be lifted, he produces a tag question in line 1 ("did you follow?"), which is a question used to indicate a common experience (Heinemann et al., 2011). Through this question the teacher seeks confirmation from student 1, which he also receives in line 2. In line 3, the teacher then begins a longer instruction (lines 3-12) where he, through the simultaneous use of speech and body, instructs student 1 how the student should position the body in relation to the window when it is to be lifted up from the floor. During this instruction, the teacher keeps holding the window with his hands, thus emphasizing that he still has the floor (Day & Wagner, 2014). This embodied conduct also gives him the opportunity to show the student visually how to position the body in relation to the window when lifting it in an ergonomic sustainable way.

In line 3, the teacher says that the student must have "more body behind", a turn that the teacher also produced just before we enter the example. As soon as the teacher has said this, he says "not like that" and at the same time places his body in line with the window (figure 1) and also places his feet on both sides of the window at the same time. In line 5, the student affirms the teacher's turn, whereupon the teacher then moves his body in relation to the window and instead places himself with both feet pointed towards the window opening (figure 2) while saying "and not like that". The student reaffirms the teacher's turn (by saying "no"). What the teacher does here is that he, both verbally and through embodied conduct, uses contrast as a didactic tool (Kilbrink et al., 2025), where the two different body positions in relation to the window exemplify and illustrate two incorrect ways of adopting an ergonomic sustainable working posture when the window is to be lifted from the floor. In line 9, the teacher then begins a turn through which he shows how the

student should place the body in relation to the window when it is to be lifted in the right way. Again, the teacher changes his body position by turning and standing at an oblique angle in relation to the window while saying “but a little bit (.) almost forty five degrees so to speak”. The student who has carefully followed the teacher’s instructions and who also has provided minimal responses such as ”yes” as ways of displaying understanding, and to reveal preference for progressivity (Stivers & Robinson, 2006), this time produces “mm” which can be described as a slightly less strong confirmation. This is also supported by the student’s follow-up statement “oh my god”, which can indicate some sort of uncertainty. The student then grabs the window and squats (figure 4) in a position that is now more in line with the position the teacher has shown as the more desirable position, compared to the position the student has previously taken.

The analysis shows how the teacher uses contrast as a didactic tool in the work of instructing the student how to lift the window in an ergonomically advantageous way, using both verbal and embodied resources simultaneously (Goodwin, 2000), and how this encourages the student to lift the window in a different way than before.

4.2. An example from the welding workshop

The second example is from a teaching session of practical TIG-welding. The OoL is TIG-welding in a welding position called PA. The expected critical aspects, a concept developed in CAVTA (Kilbrink et al., 2022), are the travel speed (the speed of the welding) and the angle of the torch. In short, the expected critical aspects are what the teacher wants the students to discern in the learning situation. Preceding the example, the teacher has demonstrated the exercise and simultaneously visualized the expected critical aspects verbally and by the use of embodied resources, in the midst of practical welding. In the demonstration he used contrast as a didactic tool (Kilbrink et al., 2025).

Example 2

1	T:	har du ett bra grepp? (.)
		do you have a good grip (.)
2	t:	((takes hold of the torch and directs it in relation to the plate))
3	T:	är det bra vinkel? (.)
		is the angle good? (.)
4	s:	((changes the angle))
5	S:	ja det tycker jag väl
		yes I think so
6	T:	[mmm jag tycker du kunde ha lite lite mer (.) så såja (.) där (.)
		[mmm I think you could have a little little (.) so like (.) that (.)
7	t:	[((takes hold of the torch with left hand, the student's hand with right hand changing the angle))
	fig:	figure 5
8	S:	okej
		okay
		((2 minutes and 44 seconds excluded from the excerpt))
9	T:	kör för fort då så får vi se vad som händer (.)
		go too fast then and we will see what happens (.)
10	t:	((lowers visor))
11	s:	((lowers visor, lights the arc))
12	T:	å när du ser att du kör för fort (.)
		and when you see you go too fast (.)
13	S:	ja (.)
		yes (.)
14	T:	du talar om när du har bra smälta (.)
		you tell me when the weld pool is good (.)
15	S:	nu har jag bra smälta
		now I have a good weld pool
16	T:	mmm (.) å då börjar du på å gå framåt (.)
		mmm (.) and then you start to move forward (.)
		hur ser du att du kör för fort? (.)
		how can you see that you go too fast? (.)
17	S:	[det smälter inte riktigt (.)
		[it does not melt properly (.)
	fig:	[figure 6
18	T:	mmm (.) kan du avsluta (.)
		mmm (.) you can stop (.)
19	s:	[((ends welding))
20	t:	[((raises visor, turns the plate))
21	s:	[((puts the torch in the holder))
22	S:	[det blev inte
		[it did not
23	T:	[nej
		[no
24	S:	genomsmält
		burn through
25	T:	nej
		no

Figure 5

Figure 6

The example starts with a dialogue about the way to hold the torch (lines 1-8). In figure 1, the physical setting of the situation is portrayed. Thus, part of the contextual configuration (Goodwin, 2000) is displayed. The teacher has positioned himself kneeling next to the student, at a 90 degree angle from the student and aligning him in the same height, thus enabling them to look at one another. The positions of the teacher and the student facilitate for them to look at and touch the artefacts, such as the torch and the plate. By this physical arrangement, the participants have created "a public and visible locus for the organization of shared attention and action" (Goodwin, 2007, p. 58). In short, the physical arrangement has opened up for the use of multiple semiotic resources. In CAVTA, dialogue is to be encouraged (Kilbrink et al., 2025) and the arrangement set up here facilitates the dialogue.

By the first question (line 1), the teacher orients towards the student's grip of the torch, thus directing the student's attention. The orientation is further made relevant when the teacher grabs

the torch directing it towards the plate (line 2). The next question (line 3) focuses the expected critical aspect (Kilbrink et al., 2022), the angle of the torch, and joint attention (Goodwin, 2007) is visible by the student's reply, both orally and by him changing the angle (lines 4 and 5). In these lines the student displays his understanding of the expected critical aspect, using the semiotic resources of his speech, and by the embodied conduct – his hand and torch movements. The teacher then corrects the student's grip both physically and in speech (lines 6 and 7). Thus, he indicates that the angle of the torch is not completely right and he opens up for the student to discern the expected critical aspect by the use of contrast (Marton, 2015). The student acknowledges his understanding by keeping the modified angle and by replying "okay" (line 8).

From line 9, the example addresses the student's actual welding in action, including the expected critical aspect the travel speed. In a sequence preceding this example, the student has been instructed to weld too slow. Here (line 9), the teacher instructs the student to weld too fast, thus directing their joint attention to the aspect of the travel speed, which is indicated by them almost simultaneous lowering their visors (lines 10 and 11). Just like the case with the angle of the torch, the teacher uses contrast to support the student's discernment "go too fast" (line 12). While the student welds there is a continuous dialogue (lines 12-19). The dialogue returns to the travel speed (line 16) when the teacher orients towards the movement forward. While still welding, the student displays his understanding by answering "it does not melt properly" (line 17). The displayed understanding and skills are also embodied as the student in combination uses his sight and arm/hand movement in the welding. The orientation towards the results of moving too fast is kept in the dialogue after the student has stopped welding and the teacher turns the plate (lines 20-25). Their swift, almost simultaneous, agreement displays what in conversation analytic terms is called mutual understanding (Sidnell, 2013).

The salient features of example 2 include dialogue and contrast as didactic tools (Kilbrink et al., 2025). The use of these tools is multimodal – the teacher and the student negotiate towards a mutual understanding using several semiotic resources (Goodwin, 2000), such as speech, embodiments and artefacts. Thus, the student's discernment of the expected critical aspects (Kilbrink et al., 2022) is displayed.

5. DISCUSSION

The use of the concept practical objects of learning is somewhat problematic – it implies a differentiation between an object of learning which is theoretic, and another which is practical. However, we align with the assumption that practical knowledge cannot be separated from the thinking process needed to conduct practical tasks (Molander, 1993; Carlgren, 2015), such as the ones addressed in this study. Moreover, we believe the paradigm of theoretical and practical knowledge to be unfortunate, since it might be part of the reason why there is a knowledge gap regarding teaching and learning processes in technical vocational education – the few practice-based studies exploring practical objects of learning might be due to theoretical knowledge being ranked higher in status (Carlgren, 2015). The overrepresentation of immigrants (Andersson, 2019) and students with incomplete or low grades from compulsory school (Korp et al., 2025) ought to motivate the reverse; there are reasons to believe that these students need innovative pedagogic approaches to reach their learning goals, and hence there is a call for knowledge contribution in the field.

In summary, the results of this study show how the teachers with the support of the pedagogic approach CAVTA use both verbalization and embodied movements to visualize the specific critical aspects of the learning situation and how the students are encouraged to display their understanding in multimodal ways in the dialogue. Thus, the study shows how elements of thinking while doing – something which is sometimes called tacit knowledge (Polanyi, 1997) – can be addressed in learning situations. The use of the pedagogic approach CAVTA (Kilbrink et al., 2025) helps the teacher to focus the teaching sessions and creates a learning situation where the interaction between the teacher and the student is rich with opportunities for them to negotiate towards a mutual understanding, not separately relying on their speech or the results after having conducted an exercise. Instead, the interaction is constructed by intertwined multiple semiotic resources in the midst of conducting the exercises. The variation in ways of visualizing and displaying understanding of focused objects of learning that CAVTA entails seems promising for teaching and learning processes of practical objects in technical vocational education. This might be particularly important, since the group of students in vocational education is heterogenous (cf. Andersson, 2019; Korp et al., 2025). The pedagogic approach CAVTA is new, but the promising results we have presented might spur on to further explorative studies. It is our belief that the approach might be suitable for teaching and learning situations of practical objects in many technical vocational education programs.

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EXPERIENCES IN PEDAGOGY OF DESIGN; "Research and Design teachers and students frame of reference about conducting Research within Design assignments "

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This study explores how students and teachers in the Dutch secondary STEM subject Research and Design (R&D), taught at schools with the Technasium Designation, differentiate between conducting Research—actively experimenting and testing to generate new insights—and gathering knowledge—searching for and collecting existing information—when working on a Design project. The basis of R&D learning is a Design or Research project, developed by R&D teachers in collaboration with a client and an expert in a relevant professional field. The focus of this study are Design projects in which students work in teams to search for knowledge, examples, user needs, inspiration, and solutions to develop the best possible Design while trying to understand the given problem. In this way, students work in a way like Designers, who by exploring data and features, explore ideas and directions to solve the problem. However, when writing Design projects, teachers often refer to both systematic Research within Design as well as gathering existing information for Design as "Research", even when the latter only involves obtaining available knowledge rather than conducting structured investigations. For example, gathering general and existing knowledge about what is already known about user preferences and needs concerning the project or Design is different from actively seeking new knowledge by conducting a structured survey about the needs and preferences of the users with respect to the Design target group. Another example is the difference between seeking information about which materials are most suitable for the working model compared to building different versions of the working model and performing A/B testing to determine which configuration works best. This raises questions such as: What criteria determine whether Research or gathering information is taking place during a Design process? In what ways do R&D teachers and students distinguish the concept of Research and searching for information in Technasium Design projects? What is circumscribed as Research by R&D teachers in Technasium Design projects? Recognizing the difference between gathering existing information for Design and conducting Research within Design is important in Design-Based Learning (DBL) because it helps clarify learning goals, assess results, allocate resources effectively, manage expectations, make informed decisions, improve collaboration and communication, and promote critical thinking.

STEM, Subject Research and Design (R&D), Concept, Research, Pedagogy of Design

1. RESEARCH & DESIGN (R&D) PROJECT BASED LEARNING

A core goal of the Dutch secondary STEM subject Research and Design (R&D), which in Dutch is called O&O (Onderzoek & Ontwerpen), is to have students work in a cooperative team involved in real- life problems set by interdisciplinary companies or organisation while learning about different technical professions. The professional companies that own problems are not necessarily involved in engineering but do need engineering support. The company or institution provides these tasks in consultation with a teacher through project assignment descriptions. As there are no textbooks for this subject, for each project a unique assignment is written, supported by the client, which is then used instead of a text course book. There is no fixed basis and diverse, changing and new projects form the basis for learning in R&D education. In the lower grades, these project assignments are written by the teacher (in consultation with companies, field experts, and/or institutions). However, in the upper grades, as part of their R&D studies, students take a more active role: they find problem owners themselves and develop per team their own project assignments in consultation with the company or institution. The projects run for about ten weeks in the lower grades (in grades 7–9, ages 12–15); and in the upper grades for 16 or 20 weeks (in grades 10–12, ages 16–18). R&D is taught in lower and upper secondary education as an elective subject at schools with the Technasium Designation.
Projects assignments have a common structure consisting of few sections: the assignment, the assignment subtasks, information about professionals and assessment. The assignment part includes information about the client, the case description, context, and the assignment itself. The assignment subtasks part covers development subtasks and completion goals. Information about the professionals responsible for solving the assignment also includes the educational path to become such a professional. Finally, there is an assessment of the product (teamwork resulted in Design or answer on research question) and the general process of cooperation, engagement, competence etc. (individual). Student learning is supported by teachers through coaching during the Design or Research project. Therefore, Research and Design projects in the lower grades are written by teachers supported by specialist in the field of the proposed problem within different engineering disciplines, such as architecture, software Design, civil engineering, industrial Design, etc. Project assignments ought to be written on the level of educated adult professionals asked to solve the problem within a engineering field and are therefore not being adjusted to students' age or skills level. As each project focuses on a different discipline within engineering and technology, students take the role of technical experts, often engineers, in that field. Although the projects are divided into projects with focus on Research or Design, there is a connection between them. To describe connection and interaction between Research and Design, it is important to first clarify what is meant by 'Research' and by 'Design'.

1.1 Obtaining new factual knowledge

Research has been defined in a number of ways, and while there are similarities in definition, there does not appear to be a single, all-encompassing definition that is embraced by all who engage in it. Grover (2015) describes Research as follows: ''Research, in its simplest terms, is searching for knowledge and searching for truth. In a formal sense, it is a systematic study of a problem attacked by a deliberately chosen strategy. This definition emphasizes that the main purpose of Research is to obtain new factual knowledge following carefully chosen study methods. Another definition of Research is given by John W. Creswell (2008), who states that "Research is a process of steps used to collect and analyse information to increase our

understanding of a topic or issue. It consists of three steps: pose a question, collect data to answer the question, and present an answer to the question." Klahr and Dunbar (1988) also discuss the three core processes of Research: formulating a hypothesis, conducting experiments, and evaluating the results. Next to named three core process Blessing & Chakrabarti (2009) stress that a clear problem definition is crucial for goal-oriented Design and Research.

1.1.1. Research

According to Creswell and Creswell (2018), Research begins with a clear purpose or objective, such as understanding the impact of a policy or intervention. This purpose guides the direction and focuses of the entire study. The objective explains why the study is done and what it aims to achieve. This also highlights the difference between pure scientific and applied Research. Pure scientific Research seeks to generate knowledge, while applied Research uses that knowledge to solve practical problems. Both must follow a scientific and verifiable approach. According to Stokes (1997) there are not two, but three categories of Research based on two binary dimensions: first dimension is a search for knowledge as a basic understanding of world around us and second, a consideration of use. That way we can distinguish four quadrants obtaining: a pure basic Research, pure applied Research, use-inspired Research, and pure tinkering as playful, creative way of learning through experimentation with materials and tools. Stokes used three big scientists as an example for each quadrant. The work of Thomas Edison reflects a scientist who specializes in problem solving and practical inventions, an example of the applied Research quadrant. The work of theoretical physicist Niels Bohr represents the basic Research quadrant, in which Researchers pursue fundamental knowledge with little concern for application. The Research of Louis Pasteur is typical of the work of scientists who pursue fundamental knowledge and select their questions and methods based on their potential relevance to real-world problems. Pasteur's studies in bacteriology were commissioned by the French wine industry. This quadrant introduced by Stokes (1997) and named Pasteur's quadrant is useful in distinguishing various perspectives within science, engineering, and technology.

Although we can distinguish different goals and perspectives of Research Verschuren & Doorewaard (2015) emphasize that a scientific and applied Research Design must be systematic and well-structured. A study should follow a clear, planned, and replicable method. All decisions made throughout the Research process should be explicitly stated and justified, so that readers understand what was done and why. Creswell and Creswell (2018), emphasize that transparency in Research is essential to ensure the verifiability and reliability of Research. According to Creswell (2014), conclusions are based on systematically collected, valid data within both applied and scientific Research (observations, interviews, documents, etc.). Verifiability and replicability are particularly important for the credibility of Research emphases Booth et al. (2016)). In addition to systematic Research that is transparent and verifiable Creswell (2014) explain that theory development and literature Research form the basis for Research questions and analyses.

1.1.2. General description of Research

In summary, Research can be generally described based on information distinguished from literature, by several key features: it is systematic, transparent, based on valid data collection, verifiable and replicable, and grounded in a theoretical basis with clear relevance. There can be recognised few steps in the process of searching for new facts: problem definition, Research question or hypothesis, execution of the Research, and answering the Research question through conclusions.

1.2 Creating solutions

The Accreditation Board for Engineering and Technology (2015) states that engineering Design is the process of Designing a system, component, or process to meet a desired need and to achieve technical problem solving. According to Moore (2014), Design processes are central to engineering practice. This means that in each discipline, the focus of Design is slightly different. As the approach to Design often depends on the discipline, it is why Design is frequently defined within the context of a specific field. For example, from perspective of ICT according to Paul Ralph end Yair Wand (2009) is Design an activity. Within architecture Van Dooren, et all. (2013) allege that in general Designing is conceived as a complex, personal, creative, and open-ended skill. Industrial Designer Cross (2006) defines Design as "the conception and realisation of new things" .

1.2.1. Design

Although definitions on Design differ there are aspects of Design that are overall considered important (IDEO, 2023; Klapwijk and Stables, 2023). Designing is conceived as a complex, personal, creative, and open-ended skill. For experienced Designers, the process of Designing is not split up in separate steps and actions (van Dooren 2013). Lawson (2006) emphasizes "Design intelligence," the ability to create solutions that do not yet exist. Schön (1983) introduced the term "reflective practitioner," describing professionals who learn by reflecting in and on their actions that correspondent with IDEO's Design Thinking approach (2015) which stresses the importance of rapid prototyping to learn and improve. In summary, the goal of Design is to develop or improve products or services (De Vries, 2005).

These definitions highlight the structured yet flexible nature of the Design process, focused on creating effective and evolving solutions. In general, Design can be characterized by few key features: it is problem-explorative, solution-oriented, goal setting, context-driven, user-cantered, iterative, creative, and reflective. According to Best (2010) there is no process model that could fit Design phases of most cases. Models must constantly be changed and adapted depending on context, a Design brief or project specifics. Despite this lots of models are made to capture a phases of Design. If we see the model as a standardized idea and not as a recipe for Design steps, we can draw inspiration from it. One of models is Double Diamond schema (Design Council 2018). It pictures problem-solution situation in few phases: Discover, Define, Develop and Deliver. Discover represents a problem understanding and analysis. Define represents knowledge gathering and formulating a Design brief. Develop includes a creative problem solving and experimentation phase and Define is a phase of elaboration, testing out different solutions and making technical drawings, schematics, or final versions. Discover and Develop phases are divergent in search for knowledge and understanding. Define and Deliver are convergent focusing on answers and solutions. .

1.1.2. General description of Design

In summary, Design can be generally described based on information distinguished from literature, by several key features: it is problem-explorative, solution-oriented, goal setting, context-driven, user-centred, iterative, creative, and reflective. Few steps can be recognised in the process of searching for new facts: insight into and analysis of the problem, knowledge acquisition, creative problem solving and developing solutions

1.3 Research and Design

As stated in previous sections Research and Design have a different goal; Research is looking for new facts and "truth" while Design is focused on developing or improving products or services. In general, they both go through few similar stages. Although different in their goals both begin with understanding and analysing the problem. Blessing & Chakrabarti (2009) stress that a clear problem definition and analyses is crucial for purposeful Design and Research. Describing the situation, identifying the core problem, and explaining the context or motivation. Next step is a collecting relevant information, literature, and background knowledge before formulating a programme of requirements (for Design) or a Research plan (for Research). Booth et al. (2016) highlight the role of a thorough literature review in establishing Research relevance and direction. By gathering a lot of knowledge about and around the problem or question to be solved, they try to lay a solid foundation for formulating Design goals and restrictions or Research questions and methodology. In next phase takes the actual iterative development of the Design or the execution of the Research, in a systematic way. Actual development of the Design or systematic execution of the Research takes place following structured steps. Lawson (2006) notes that Design involves creative problem-solving and experimentation. Creswell (2014) explains how Research is conducted systematically based on methodology. This is followed by making definitive Design or drawing Research conclusions, which are then presented to the public with the aim of informing or persuading. Cross (2006) discusses the importance of evaluation and reflection to refine and validate Design solutions. Analysing results, drawing conclusions, and refining the final product or insights. In short, both Research and Design follow a process that begins with problem exploration followed by knowledge gathering and continues with conducting Research or Designing a solution and concludes with drawing conclusions and presenting the findings.
Described phases have the same goal in general, such as understanding the problem, but for Design or Research they have different interpretations. For example, while acquiring knowledge in Design leads to a clear Design brief and setting up final Design goals, in Research it will result in a clear main Research question and Research plan.

Table 1 General Division of Research and Design Phases and their Outcomes

Design or Research phase	Activity	Outcome
Problem Analysis	Describing the situation, identifying the core problem, and explaining the context or motivation.	Design brief Research question.
Knowledge Gathering	Collecting relevant information, literature, and background knowledge formulating goals and strategies	Clear formulated Design goals Well-founded Research plan
Design Phase or Research Execution	Actual iterative development of the Design or systematic execution of the Research,	Design concepts, prototypes, models. Collected data and/or results
Elaboration and Conclusions	Analyzing results, drawing conclusions, and refining the final product or insights, final versions.	Finalized Design... Well-founded conclusions

During a process of Research and Design is very important to continuously reflect on work and communicate the process and outcomes clearly to inform or persuade the intended audience (e.g., client, teacher, peer group, co-worker etc.).

2. RESEARCH WITHIN DESIGN PROJECTS

In the Dutch Secondary Education Subject Research and Design (R&D) Technasium curriculum, teachers often refer to the exploring data and understanding the problem within Design projects —where students gather knowledge and analyse the Design problem—as "Research." That is not unusual, as Research does play a role within Design in various ways — for example, it is often an integral part of the Design process for examining material characteristics, to obtain data about users, testing usability or conducting empirical investigations. Frankel and Racine (2010), for example, explain the function of Research within Design with the term Research for Design, to enable Design. Designing also frequently involves exploring prior studies, analysing trends, and consolidating relevant information, gathering, and synthesizing existing insights crucial for Design decision-making rather than conducting Research. Despite this distinction, educators and practitioners still classify this process as Research within Design, leading to an interesting paradox: Why is the collection and analysis of pre-existing knowledge perceived as genuine Research in the realm of Design? The confusion surrounding the nature of Research in Design education forms the basis of this study, highlighting the need for clearer distinctions between Research (which seeks new knowledge) and exploration (which synthesizes existing knowledge for practical use). Focus is on the initial understanding and perception of concept of Research within Design projects. What are the existing ideas and to what extent do they correspond to already confirmed. What criteria determine whether Research or gathering needed information during a Design process within Design project is taking place.

3. METHODS OF RESEARCH

This Research explores what teachers and students understand as concept of Research within a R&D Design projects and whether teachers and students have a shared understanding of concept of Research within Design projects. The Research will have two components: one part will be conducted through analysis of R&D Design projects to investigate how Research is described and used in Technasium Design projects.

Analysing R&D project descriptions will be based on criteria from literature and examining how actual Research or the retrieval of existing information is reflected in the descriptions, assignments within Design projects. Research focuses on lower grades of secondary education Design projects written by teachers. This is very important because their descriptions and understanding form a base for student self-written project in upper classes. From twelve schools which are mainly located in South Holland, three Design projects per school will be analysed on the use of the concept Research in the context of Design project description. In total the thirty-six projects will be examined to get an overview of: for which school year is assignment written, professional fields assignments are from, where in the project description is Research asked, clarity of main Design assignment, how is the concept of Research described, complexity of

Research, what method of data gathering is required, in which phase of Design process is Research asked, which goal serve asked Research approach and is knowledge asked to gain or synthesizing existing knowledge for practical use.
The second part of the Research is based on surveys with a goal to examine an understanding of students and teachers' concept of Research within Design. Surveys will be conducted among three focus groups; 20-30 starting students R&D in the lower grades (in grade 7, ages 12-13); 20-30 experienced students R&D in the upper grades (in grades 10 and 11, ages 16–17) and a 10-15 R&D teachers. Survey will follow, next to general data like a school level (upper of lower class) and student or teacher, general parts of Design process with focus on Research descriptions within a part of general Design process. For example, students and teachers will be asked to note, define of explain does Research finds place within asked part of Design process and in which form.

4. EXPECTD RESULTS

This research aims to provide insight into the current understanding of the concept of research during the execution of the design projects, the application of the concept of research within design and the collection of necessary information in Technasium projects. As it is a work in progress, so data has been collected or still needs to be collected and analysed. The expectation is that within design projects the patterns of requested actions that emerge as Research will become clear and that we can compare these with the images that students have of research within design.

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Enhancing Academic Trajectories: A Machine Learning Framework for Optimized Student Placement

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Abstract. In the context of increasing enrollments and concerns over student retention in higher education, this study introduces a machine learning framework designed to optimize student placement in academic programs. Addressing the challenges posed by the surge in student numbers and the complexities of matching student profiles to suitable programs, the proposed methodology leverages data analytics to predict student success and mitigate dropout rates. The framework facilitates the creation of student profiles and employs machine learning techniques to align incoming students with optimal academic paths, with the goal of fostering a more effective and personalized educational environment.

Keywords: Student retention · Machine learning · Academic placement · Higher education · Student profiling · Dropout prediction · Educational data mining

1 Introduction and Motivation

The landscape of higher education is rapidly evolving, driven by increased global enrollment and the complex challenges of student retention. According to UNESCO, global tertiary enrollment rose from 28.5 million in 1970 to an estimated 235 million by 2023 [1]. For instance, in France alone, 2.97 million students registered for higher education in the 2021–2022 academic year, marking a 2.5% increase from the previous year [2].

However, this growth has not been accompanied by improved success rates. Data from the 2010–2011 Bachelor's cohort in France revealed that only 39.8% of students graduated within four years [3]. This mismatch between student potential and academic program suitability is a key concern and has prompted systemic reforms, such as the introduction of the Parcoursup platform [4]. Despite efforts to improve transparency and fairness, critics argue that such platforms often fail to capture the nuanced profiles of students, thereby limiting their effectiveness.

Success in higher education is often narrowly defined by graduation rates [5]. Yet, this binary view neglects qualitative dimensions such as student engagement, intellectual development, and alignment between personal interests and academic paths. In this study, we define an "excellent student" as one who not

only excels academically but also demonstrates genuine interest and conceptual understanding in their chosen field.

This research aims to develop a machine learning framework that enhances the student admission process by predicting student success and aligning student profiles with suitable academic programs. The methodology leverages prior data to create three distinct student clusters—Bad, Average, and Excellent—and uses these profiles to predict the most suitable placement for incoming students.

While the experiments in this paper are grounded in the French academic system, the proposed framework is designed to be adaptable across international education systems. Cultural and institutional differences are acknowledged, but universal factors like academic background, motivation, and social integration form the foundation of this study. Importantly, the objective is not to create an elitist system but to reduce academic mismatches and foster equitable opportunities for all students.

2 State of the Art

The optimization of student placement using machine learning (ML) has attracted significant research attention. Numerous studies focus on predicting student dropout as a proxy for academic risk, while others attempt to forecast academic success by analyzing historical and behavioral data. This section reviews existing literature under two major lenses: analytical approaches (focused on human and sociological factors) and predictive approaches (centered on algorithmic modeling).

2.1 Predicting Student Dropout

Student dropout has been studied extensively across sociological, psychological, and computational domains. Research shows that dropout is influenced by factors such as family background, social integration, institutional commitment, and satisfaction with the chosen program [6,**?**,**?**]. Analytical studies suggest that dropout is not merely an academic failure but a social phenomenon often tied to student support networks and mental well-being [7,**?**].

Advanced machine learning techniques such as Decision Trees (DT), Random Forests (RF), k-Nearest Neighbors (KNN), Support Vector Machines (SVM), and Neural Networks (NN) have been widely applied to model dropout prediction with accuracies often exceeding 80% [8,**?**,**?**]. However, most of these models focus on identifying at-risk students after enrollment, offering limited utility during the admission phase.

2.2 Predicting Student Success: A Human-Centric Challenge

Defining and predicting academic success is inherently complex. While institutions often equate success with graduation and grades, students may define it

through engagement, understanding, and satisfaction [5]. This divergence necessitates a holistic modeling approach that incorporates socio-psychological factors like motivation, peer relationships, and adaptability.

Multiple studies emphasize that success cannot be universally defined; it varies across time, culture, and institutional contexts. Consequently, predictive models must be flexible enough to adapt to localized definitions of excellence while ensuring fairness and transparency [9].

2.3 Analytical Approaches

Analytical literature underscores the significance of pre-admission indicators such as prior academic performance, institutional fit, and family support [10,**?**,**?**]. These variables have been incorporated into persistence models that help identify students likely to succeed or struggle. Particularly, composite models such as Tinto's and Bean's theories of student departure have inspired multifactor frameworks for dropout analysis [11,**?**].

2.4 Predictive Approaches Using Machine Learning

Studies employing ML for student modeling have shown promising results. Decision Trees and Random Forests offer interpretability, while Neural Networks and SVMs provide high predictive accuracy for complex, nonlinear data. The Synthetic Minority Over-sampling Technique (SMOTE) has been applied to mitigate class imbalance, especially when identifying rare but valuable categories like "excellent" students [12].

Some frameworks even utilize Natural Language Processing (NLP) to analyze qualitative inputs such as motivation letters, enabling a richer understanding of student intent and capacity [13]. Table 1 shows the frequency of ML models used across reviewed studies.

Table 1. Common Machine Learning Models Used in Literature

Technique	**Frequency**
Decision Tree (DT)	49
Neural Networks (NN)	29
Logistic Regression	25
k-Nearest Neighbors (KNN)	9

These models each have strengths and trade-offs. For example, DTs offer explainability, while NNs perform well with high-dimensional data but lack transparency. The best model for deployment must be chosen based on institutional context and available data.

3 Framework and Methodology

This section outlines the architecture of the proposed machine learning (ML) framework designed to optimize student placement during the admission process. Our approach integrates both supervised and unsupervised ML techniques to classify students into three categories: **Excellent**, **Average**, and **At Risk**. The workflow is composed of data preprocessing, clustering, outlier detection, and prediction layers, each powered by distinct algorithms suited for its task.

3.1 Algorithm Selection

Based on our literature review, the following algorithms were selected for their complementary strengths:

- **Neural Networks (NN)**: Used to process unstructured data such as motivation letters and convert it into numerical embeddings.
- **Principal Component Analysis (PCA)**: Applied for dimensionality reduction and improved efficiency.
- **K-Means Clustering**: Groups students based on feature similarity into predefined clusters (Excellent, Average, At Risk).
- **Isolation Forest (IF)**: Identifies anomalous profiles that deviate from the majority—typically outliers such as exceptionally strong or weak candidates.
- **Lasso Regression (LR)**: Performs feature selection and highlights variables that most influence classification.

3.2 Workflow Architecture

The data pipeline is structured into modular blocks, as shown in Figure 1, enabling transparency and flexibility.

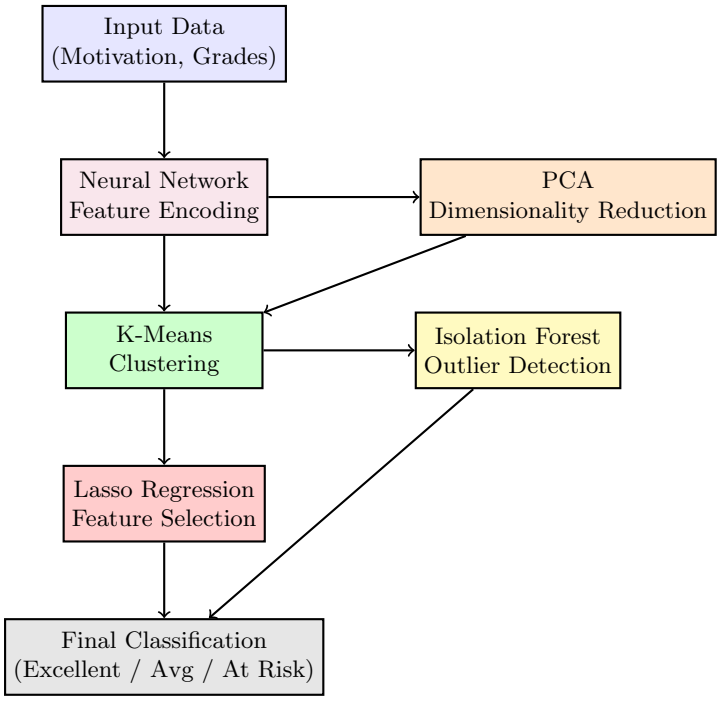

Fig. 1. Algorithmic workflow for student success prediction.

3.3 Input Data Types

The system is designed to ingest three categories of data:

- **Motivation Letters:** Parsed with Natural Language Processing (NLP) and converted to vectorized embeddings using NN.
- **Academic Performance:** Includes prior grades, degree levels, and education system types.
- **Program Metadata:** Institutional data describing formation difficulty, competitiveness, and learning model.

3.4 Cluster Assignment and Labeling

Each student is assigned to a cluster through K-Means based on similarity to historical profiles. Isolation Forest identifies extreme deviations, and Lasso Regression interprets the importance of features, helping in both validation and refinement of clusters.

3.5 Modularity and Reusability

The framework is intentionally modular. Depending on institutional goals or regional constraints, models can be re-trained with local data. Moreover, the

system allows toggling of sensitive inputs (e.g., socio-demographic details) to remain compliant with ethical guidelines.

4 Conceptual Proposal and Validation

To translate the proposed machine learning framework into a deployable system, we conceptualize a three-part pipeline that integrates with existing university registration infrastructures. This section outlines the data ingestion requirements, modular design, and validation approach, as well as ethical considerations for real-world application.

4.1 System Overview

The system is designed to operate at the intersection of institutional registration data, program metadata, and applicant information. The goal is to output a recommendation indicating the applicant's suitability for a program based on past data and clustering logic.

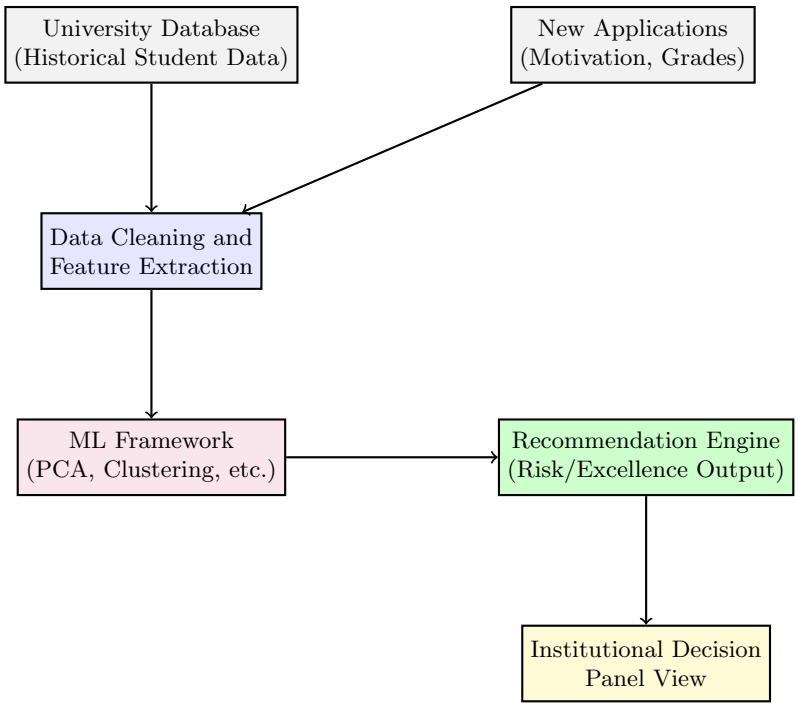

Fig. 2. Conceptual deployment of the student placement framework.

4.2 Feeding the Model

The system requires three types of data inputs for optimal performance:

- **Historical Student Profiles:** Past students' academic performance and outcomes for supervised learning.
- **Application Materials:** Including motivation letters and transcripts from incoming students.
- **Program-Level Information:** Metadata such as dropout rates, GPA thresholds, and pedagogical style.

4.3 Validation Strategy

To assess the reliability of the framework, a two-phase validation process is proposed:

1. **Retrospective Validation:** Apply the model to historical datasets where student outcomes are known. This phase verifies if the framework can classify students accurately into their eventual performance groups.
2. **Prospective Validation:** Use the model during ongoing admissions and monitor how classified "excellent" students perform over time.

Performance metrics such as accuracy, precision, recall, and ROC-AUC scores will be calculated and monitored continuously to refine model thresholds.

4.4 Ethical and Operational Considerations

To ensure fair deployment:

- No personal identifiers (name, nationality, gender) are used during model training or inference.
- Admissions committees must not be exposed to feature weights or decision rationales to prevent bias.
- Recommendations are advisory, not mandatory. Human discretion remains in the loop.

4.5 Scalability and Generalization

Although developed with the French university system in mind, this framework can be generalized to any academic institution by training on localized data and refining definitions of success. Institutions may customize success labels and program difficulty indicators to match their strategic priorities.

5 Implementation and Experimental Results

This section presents the practical implementation of the proposed framework using real-world data, evaluates its clustering capabilities, and discusses early findings from the experiment. The experimental setup was developed using RapidMiner to simulate data ingestion, processing, clustering, and classification workflows.

5.1 Dataset Description

The dataset used for the experiment was obtained from the Université de Pau et des Pays de l'Adour (UPPA), comprising student application data for the SIGLIS Master's program between 2019 and 2024. The dataset includes:

- Academic history (grades, diplomas)
- Admission year
- Age and year of birth
- Final mention (e.g., Très Bien, Bien, Passable)

The dataset contains 90 entries, which were cleaned and anonymized before being processed.

5.2 Experimental Setup

Due to limited data availability, the first implementation focused on clustering students into three groups: **Excellent**, **Average**, and **At Risk**. Motivation letter analysis (NN component) was omitted in this pilot due to the lack of text input. The working pipeline is shown in Figure 3.

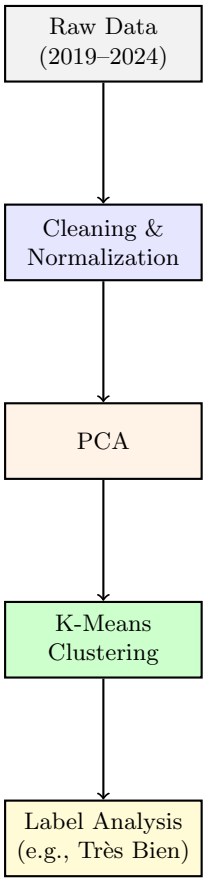

Fig. 3. Simplified pipeline implemented in the experiment.

5.3 Clustering Results

Students were clustered into three groups using K-Means. Clusters were interpreted based on their relationship to academic mentions:

- **Cluster 0:** Mostly average performance, with some missing mention data.
- **Cluster 1:** Small group with no mention and possibly incomplete records.
- **Cluster 2:** Dominated by students with a *Très Bien* (very good) mention—classified as "Excellent".

Although the dataset is small (only 90 entries), the model showed clear separation in mention quality across clusters.

5.4 Quantitative Summary

Table 2. Number of Students per Academic Year

Academic Year	Number of Students
2018–2019	14
2019–2020	13
2020–2021	13
2021–2022	17
2022–2023	32

The year 2022–2023 had the highest proportion of students with excellent mentions, reinforcing the cluster validity.

5.5 Limitations

The following limitations were encountered during this phase:

- Small dataset size hindered generalization.
- No access to textual inputs (e.g., motivation letters) limited testing of NLP components.
- Lack of final performance outcomes (e.g., GPA) made success classification dependent solely on mentions.

5.6 Early Conclusions

Despite limitations, this pilot confirms that historical student data can be clustered meaningfully. The clustering component successfully identified profiles resembling high-performance students. With richer datasets (e.g., including motivation letters, interviews, or assessments), the full pipeline could be tested and validated for deployment.

6 Conclusion and Future Work

This research proposed and implemented a machine learning framework for optimizing student placement in higher education. Through a multi-layered approach incorporating clustering, dimensionality reduction, and predictive modeling, the system aims to assist institutions in identifying students most suited to specific academic programs—thus improving both success rates and institutional efficiency.

6.1 Summary of Contributions

The key contributions of this study include:

- A literature-informed design of a modular ML framework integrating PCA, K-Means, Isolation Forest, and Lasso Regression for student classification.
- A conceptual deployment model for institutional use, preserving fairness and transparency.
- A preliminary implementation using real data from UPPA, which demonstrated promising clustering behavior based on student mentions.

The framework is built to be adaptable across institutions and cultural contexts, with flexibility to redefine "success" based on localized educational goals. Importantly, ethical safeguards are embedded in the design to avoid misuse or algorithmic bias.

6.2 Addressing Research Gaps

While the literature on dropout prediction is vast, few studies address proactive placement at the time of application. This study fills that gap by shifting the focus from detecting failure to enabling success from the outset. Furthermore, the inclusion of socio-academic indicators and modular interpretability enhances the practical utility of the system.

6.3 Limitations

Despite its promise, the study is subject to several limitations:

- The dataset was relatively small (90 students) and specific to one master's program.
- Motivation letter processing was not tested due to the absence of textual data.
- Success was defined purely based on mention or final grade, which may oversimplify performance.

These limitations restrict the generalizability of the experimental findings but do not undermine the conceptual value of the framework.

6.4 Future Directions

Several paths for improvement and expansion are proposed:

1. **Expanded Dataset:** Apply the framework to larger and more diverse datasets, including undergraduate programs, other universities, and international student pools.
2. **NLP Integration:** Incorporate neural network models to analyze motivation letters, personal statements, or interview transcripts for more nuanced profiling.

3. **Longitudinal Tracking:** Implement a follow-up system to track students over time and refine predictive labels using real performance data.
4. **Policy Integration:** Collaborate with education ministries or accreditation bodies to align the framework with institutional regulations and national goals.

6.5 Concluding Remarks

As higher education systems grow in scale and complexity, personalized and data-driven tools will become increasingly necessary to match students with academic pathways that maximize their potential. The framework presented in this work offers a structured, ethical, and modular solution that institutions can tailor to their specific contexts. With further validation and development, this approach holds the potential to reshape the admissions landscape and support more equitable, efficient, and successful academic journeys.

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Engineering Playworld: A model of practice to engage kindergarten children in engineering thinking

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Abstract: Based on Vygotsky's cultural-historical theory, engineering playword is a new model of practice aiming to stimulate young children's initiative in participating in engineering practical activities and learning engineering concepts through collective imagination and role-playing. This study combines interview, observation, and video analysis methods to record and analyze young children's engagement in the engineering playworld, thereby providing suggestions for preschool teachers on promoting the development of engineering thinking of young children. This study finds that with the conditions created by the engineering playworld young children actively participate in engineering practices and grasp engineering concepts in imaginative play scenarios. They are capable of taking the initiative to identify problems, design solutions, select appropriate materials, and test and improve their outcomes, collaborating with others to achieve play objectives.

Keywords: Engineering playworld; young children's engineering thinking; imaginary play; cultural-historical theory

1. Introduction

1.1 The importance of early childhood engineering education

Currently, in many countries, knowledge and professional skills in Science, Technology, Engineering, and Mathematics (STEM) disciplines have become increasingly important as a societal goal. UNESCO's publication *Exploring STEM Literacy for the 21st Century* identifies "problem-solving and engineering thinking" as core elements of STEM skills. It is evident that engineering thinking, as one of the triadic thinking modes (comprising "scientific thinking, technological thinking, and engineering thinking"), has become an essential cognitive quality for students in the 21st century. In the United States, the Committee on K-12 Engineering Education (CEE) was established as the primary leading body for engineering education in K-12 schools. As early as two decades ago, scholars proposed incorporating engineering education into the elementary school curriculum, which offers children avenues to connect, apply, and reinforce their knowledge in math, science, and design (Rogers & Portsmore, 2005). In 2009, the CEE released *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, which provided specific policy recommendations and practical principles for effectively conducting and implementing engineering education in primary and secondary schools.

In 2022, China's Ministry of Education issued the *Science Curriculum Standards for Compulsory Education*, which proposes six learning content areas related to technology and engineering, encouraging students to develop independent inquiry and problem-solving skills through practical activities. In conclusion, to meet the demands of future society for talent, it is imperative to cultivate students' engineering thinking abilities as a core task and fundamental content of engineering education.

1.2 Engineering thinking

In 2006, the U.S. National Academy of Engineering (NAE) and the U.S. National Research Council (NRC) convened a special committee to explore the question of "how engineering should be taught in K-12 education." The committee released a report in 2009 titled *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. The report defines engineering thinking as "the thinking habits of engineering," which include "systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations." These are often regarded as fundamental skills for citizens in the 21st century.

In 2014, the Royal Academy of Engineering (RAE) in the UK published a research report titled *Thinking Like an Engineer: Implications for the Education System*. The report outlines six key *Engineering Habits of Mind*: creativity, systems thinking, optimism, collaboration, communication, and ethical considerations. The state of Virginia in the United States implemented a project named EFK (Engineering For Kids). This project holds the belief that children learn to solve problems through a process of "asking, imagining, planning, creating, testing, and improving". In 2006, the educational department of Massachusetts designed a project called EIE (Engineering is Elementary) to engage children aged 3 to 6 in "engineering for kindergarteners". This project introduced the EDP model (Engineering Design Process), which begins with "exploring the problem," followed by "selecting applicable criteria" based on the problem, then proceeds to "design and create", and finally concludes with "testing against criteria" and "improvement".

Based on the aforementioned definitions of engineering thinking and young children's engineering activities, this study defines young children's engineering thinking as a comprehensive way of thinking related to active exploration and creativity that is required when they solve practical problems and engage in engineering construction activities. It encompasses four dimensions: designing, making, testing, and collaboration.

1.3 Engineering playworld

Based on Vygotsky's cultural-historical theory, Swedish scholar Lindqvist (1996) established the pedagogy of the 'Play World' in Swedish preschool institutions. This approach allows both children and adults to enter story-based imaginative scenarios and collectively solve dramatized problems, while underscoring the active role teachers play in transforming the environment of children's play.

In order to explore the integration of play and STEM learning and facilitate children's learning of STEM concepts, Fleer (2018) has expanded upon the original 'Play World' approach by incorporating elements of engineering, mathematics, science, and other disciplinary concepts, developing it into the method of 'Conceptual Playworlds'. Fleer (2021) considers Conceptual Playworlds as a programmatic framework for achieving learning objectives within play-based teaching scenarios. In a Conceptual Playworld, children and teachers, by assuming roles from selected stories, create meaningful and emotionally charged actions. Together, they explore and resolve problems that arise within the imagined play scenarios.

The Engineering playworld refers to a model of practice, where teacher and children jointly create imaginary scenarios with the engineering principles embedded into the play. The dramatic nature of the

imaginary scenarios serves as a driving force for children to seek engineering solutions. Children actively apply engineering principles and concepts to solve problems encountered in the imaginative play. This model of practice facilitates a natural integration of engineering learning with children's interests and enhancing the personal meaning of learning those engineering concepts.

2. Method

2.1 Research Questions

This study aims to conduct practical research on the Engineering playworld, observing and analyzing young children's behaviors across the four dimensions of designing, making, testing, and collaboration when they solve problems within imaginary scenarios and engaging in engineering construction activities in the Engineering Playworld.

(1) How do children's engineering thinking emerge through the engagement in Engineering Playworld?
(2) What conditions does Engineering Playwold create to facilitate children's engineering thinking?
(3) What are the practical and effective suggestions for early childhood educators to adopt the Engineering Playworld?

2.2 Participants

29 children aged 5-6 and their classroom teachers from H Kindergarten in City N participated in this study. A two-month Engineering Playworld program was conducted, with comprehensive observation and recording carried out throughout the entire process. Prior to and during the research, full informed consent was obtained from both the children and their parents, and the children were allowed to voluntarily withdraw from or rejoin the study at any time. Based on the class's thematic activity of "transportation methods in China" and the children's interest in "transportation," the researcher selected the story of *Zheng He's Voyages to the Western Seas*. This story was derived from a real historical event, featuring a rich array of character roles and diverse, engaging plots. The story also contained abundant STEM (Science, Technology, Engineering, and Mathematics) concepts, particularly those related to design, construction, and problem-solving experiences.

2.3 Data collection

The participating teacher's perspectives on the development of children's engineering thinking within the Playworld and the insights gained from implementing the Playworld were collected via face-to-face interview. The emergence of children's engineering thinking during the Playworld were observed and recorded via the *Observation Scale for Children's Engineering Thinking in the Engineering Playworld*. The researcher primarily adopted participatory observation to gather relevant data, utilizing the anecdotal record method while engaging in engineering Playworld activities with the children. The participating teacher's and children's engagement and performance were captured by two digital cameras, with one focusing on the group work and another focusing on the entire classroom. The total video duration is approximately 1,000 minutes.

2.4 Data analysis

As the initial analytical step, the researcher organized the original video data into situational time segments related to children's engaging in design activities, building with blocks in the construction area, making and creating activities, and collaborating with teachers or peers. In the next stage, theoretical

concepts were utilized to investigate the development of children's engineering thinking, identifying children's performances in four aspects: design, making, testing, and collaboration. Finally, the interactions between teachers and children in the context of the “Zheng He’s Voyages to the Western Seas” play scenario were analyzed, explaining how the playworld facilitated the emergence of children’s engineering thinking.

3. Results

3.2 Emergence of engineering thinking

Based on the observation of the engineering playworld activities conducted in this study (building a dock, making a code-locked box, building a cannon, and crafting a birdcage), combined with the *Observation Scale for Children’s Engineering Thinking in the Engineering Playworld,* the participating children’s emergence of engineering thinking was analyzed in terms with design, making and creating, testing, and collaborating.

Design

In this study, children’s design is defined as the ability to observe and identify problems that need to be solved, and then, based on the demands of the problem context and available resources, collaborate with peers or teachers to devise appropriate and simple solutions. This process encompasses three key elements: identifying the problem, understanding the context and conditions, and cooperatively making a plan. Across the four activities conducted in this study, the participating children’s design capabilities emerged as they took the initiative to drawing a draft plan displaying both the whole structure and its individual components.

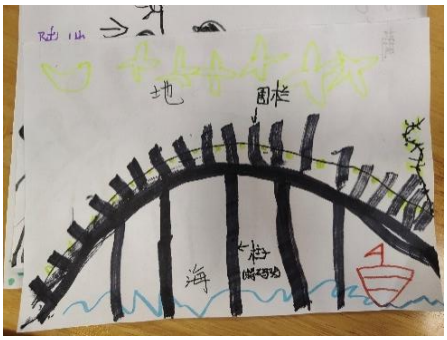

Figure 1. Children’s design of the dock

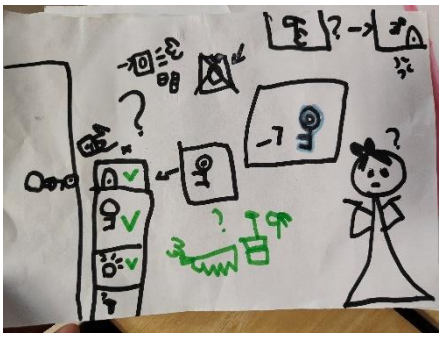

Figure 2. Children’s design of the treasure chamber lock

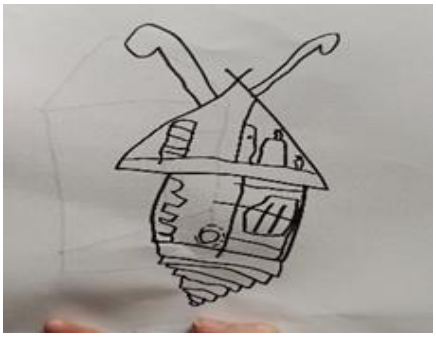

Figure 3. Children’s design of the birdcage

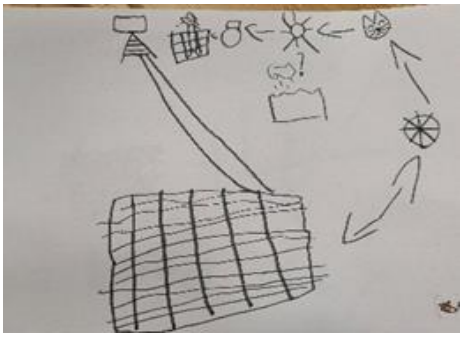

Figure 4. Children’s drawings of materials required for the birdcage

Making and Creating

In this study, children's making and creating is defined as the process of selecting simple and appropriate materials and tools based on the designed solution drawings to create simple artifacts, aiming to address problems and meet needs. This process encompasses two key elements: selecting suitable materials and tools according to the design plan, and executing the fabrication steps. Across the four activities conducted in this study, the development of children's making and creating demonstrated a progression from initially relying on a relatively narrow range of materials, seldom using tools, and constructing in a rather haphazard manner, to eventually employing a variety of materials and tools and being able to makea product in accordance with the design drawings in a step-by-step manner.

Figure 5. A password box made of cardboard

Figure 6. A catapult made of popsicle sticks

Figure 7. A birdcage made of various materials

Testing

In this study, children's testing is defined as the ability to conduct simple evaluation and testing of their fabricated products within problem-solving contexts, identify obvious issues that exist, and be willing to use both their hands and minds to attempt further improvements. This encompasses two key elements: conducting basic evaluation tests and optimizing improvements. Across the four activities conducted in this study, the development of children's testing demonstrated a progression from passively making changes under teacher guidance to actively initiating improvements and optimizations. Moreover, children's testing behaviors were mostly concurrent with the making and creating process. This was a prominent characteristic of their evaluation and testing practices.

Collaborating

In this study, children's collaboration is defined as the ability to engage in a certain degree of division of tasks and cooperation with peers during the making and creating process; willingness to accept others' suggestions as well as express their own viewpoints, and the capacity to negotiate and make decisions with peers. This encompasses three key elements: cooperating and dividing tasks with peers, being willing to express viewpoints and accept suggestions, and negotiating with peers. Across the four activities conducted in this study, the development of children's collaborative abilities primarily manifested as initially relying on simple physical coordination (such as carrying blocks and taking turns building) with a lack of negotiation, evolving into the ability to engage in reasonable division of task and cooperation; and when faced with disputes, they could negotiate based on shared emotional goals.

3.3 Conditions that engineering playworld creates to facilitate engineering thinking

Imagination—The Foundation of Children's Learning through Play

Vygotsky (2004) regarded imagination as a productive mental activity. When children create imaginary scenarios, alter the meanings of actions and objects, and endow them with new significance within these imagined contexts, mature forms of play emerge. Imagination enables young children to discover novel ways of thinking about things. In the course of play, driven by the demands of the play's narrative, children use their imagination to invent new uses for objects as props. For instance, in the play scenario themed around *Zheng He's voyages to the Western Seas*, they transformed a climbing tube into a time-traveling tunnel. Imagination liberates children from the constraints of the real world, allowing them to utilize language, symbols, and mental representations to construct new, imagined worlds—worlds that exist solely within their minds. Imaginary thinking aids children in generating new ideas and innovative problem-solving approaches, enabling them to think outside the box and devise creative solutions to past challenges.

The Engineering Playworld Enhances Young Children's Initiative in Engineering Practice:

The playworld transforms the traditional teacher-centered approach to activities, allowing children to gain a certain degree of freedom and collectively construct rules within imaginative play-based activities. It also provides teachers with an active role to support the development of children's imagination, creativity, and initiative. Furthermore, children's active participation in the playworld motivates them to address problems that arise during the play as responsible and conscious members, thereby enhancing their initiative. Within the engineering playworld, young children fully interacted with the environment, exercised their initiative, and learned design concepts as responsible and conscious participants. They utilized these concepts to confront and overcome challenges, and ultimately develop their engineering thinking.

Teachers' Dynamic Support to Meet the Needs of Young Children's Engineering Learning

In the playworld themed around *Zheng He's Voyages to the Western Seas*, both teachers and children assumed roles as characters within the story. This allowed young children to interact with the teacher not as real-life teacher-children relationships but as play partners within the imaginary context. Based on the needs of the children's play, when they encountered difficulties in solving problems, teachers provided support by linking content knowledge to the play through suggestions, demonstrations, and explanations. Conversely, when children were able to proactively resolve their own issues, teachers adopted a stance

that was “below” that of the children, observing their engineering play and problem-solving approaches. When the teacher and children were on an equal footing, they engaged in equitable negotiations and collaboratively solving problems together.

4. Discussion and Conclusion

Fleer’s studies (2021, 2022) revealed that the Playworld pedagogy creates a dramatic and socially interactive imaginary context through rich storylines. Children and adults enter collective imaginary play using psychological tools (such as climbing tubes, which serve as time-travel tunnels), assuming specific roles and embarking on adventurous journeys together. While collaboratively learning and exploring new concepts and methods to solve problems within the context, they also experience and share the emotional journeys of their characters in the story. Within this imaginary context, through dramatic narratives and interpersonal interactions, young children gain a bidirectional pathway for emotional experience and cognitive development. Imaginary scenarios imbue tasks with meaning, enhancing children’s immersive experience and sense of mission in activities, thereby motivating them to actively engage in design, making and creating, and other processes to resolve issues (Wang et al., 2023). The dramatic conflicts presented in the development of the storyline of *Zheng He's Voyages to the Western Seas* offer an outlet for children’s emotional expression, enabling them to convey feelings through language and actions. Through role interactions within the collective imaginary context, children work together towards a common goal, promoting empathy, cooperation among peers, and the development of individual engineering thinking.

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Investigating the impact of comparison difficulty and judge fatigue on the feasibility of comparative judgement for technology education

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Abstract

The use of comparative judgement (CJ), or more specifically adaptive comparative judgement (ACJ), is proposed as a solution to a critical challenge in technology education assessment – the reliable assessment of creative pieces of student work produced in response to open-ended designerly activities. However, despite several studies highlighting the high level of reliability achievable through ACJ, proportionately less effort has been given to understanding its feasibility in terms of prospective translation to practice. Understanding both whether ACJ is feasible or not, and how to improve its feasibility, is paramount in terms of future work to support its integration into practice. To examine ACJ feasibility, this paper examines whether the time taken for ACJ comparisons is impacted by the estimated difficulty of the comparison, and whether there is a fatigue effect which sets in over the course of making several comparisons. Comparison times from two CJ sessions are examined, one through an exploratory framework and the other through a confirmatory lens. The results suggest that estimated difficultly does not impact the time taken to make comparisons, and in general, judge fatigue is not an issue over circa 70 comparisons. These results suggest that ACJ feasibility efforts in technology education should focus on improving the pairing algorithm(s) to reduce the required number of comparisons, rather than making comparisons easier, which inform future directions in ACJ advancements. Further, the lack of impact of estimated difficulty raises questions concerning what influences decision making in technology education comparative judgements. It is suggested that theories around heuristic decision making may be a useful framework to explore this further.

Key Words: Comparative judgement, feasibility, fatigue, decision-making

1. INTRODUCTION

Adaptive comparative judgement (ACJ) is an approach to educational assessment which contrasts traditional criterion referenced assessment in that it is predicated on holistic judgement. Based on Thurstone's (1927) law of comparative judgement, ACJ sees multiple assessors, herein "judges",

make several binary pairwise comparisons on pieces of student work, herein "portfolios". The outcomes of these comparisons are then modelled into a rank order from "best" to "worst" (Hartell & Buckley, 2021), typically using the Bradley-Terry-Luce (BTL) model (Hunter, 2004). For a full account of the ACJ methodology, Hartell and Buckley (2021) provide a chapter on the process, and Buckley (2024) describes the initial development of an instrument for ACJ which illustrates the algorithms more clearly. Introduced to technology education through the e-scape project (Kimbell, 2007), and through a special issue of the *International Journal of Technology and Design Education* (Williams & Kimbell, 2012), ACJ is presented as a useful method of educational assessment for the field due to the prevalence of designerly and creative outputs from students. Since its introduction it has been the subject of several studies which have illustrated its ecological validity and high level of reliability (Bartholomew & Jones, 2021; Bartholomew & Yoshikawa-Ruesch, 2018), however despite this its adoption outside of research contexts remains limited.

There are several challenges to the increased adoption of ACJ over criterion-referenced assessment. A first could be the financial cost of ACJ. Although efforts are being invested to develop an open source tool (Buckley, 2024), at present it is primarily through proprietary software that people can access comparative judgement[1] (CJ) tools. A second is likely that the use of rubrics is intuitively transparent. Irrespective of whether the rubric is valid (cf. Sadler, 2009), or used reliably (cf. Jonsson & Svingby, 2007), stakeholders generally understand that the use of a rubric will lead to a result, typically a sum score or weighted sum score of the marks given against criteria within the rubric. ACJ does not have this quality. There are two algorithms running "behind the scenes" which, to non-experts (and with propriety software, everyone), are largely unknown. These are the pairing algorithm(s) which select which portfolios to present to a judge for comparison, and the model which computes the outcomes of these comparisons into the overall rank of portfolios. Resolving this will likely require much greater efforts in dissemination and explanation than is appropriate for this article.

A third significant challenge is the time cost of ACJ, or its practical feasibility, which has been under-explored to date (Bartholomew & Jones, 2021), and where it has been explored, has been so inconsistently (Buckley et al., 2022). Egelandsdal et al. (2025) recently examined this in a law education context. In their study, they gave 8 judges 35 hours each to make comparative judgements for an ACJ session, basing this decision on the typical time afforded for assessment with rubrics. They had a target of each judge making 187-225 comparisons in this time based on an estimated number of total comparisons to achieve a desired level of reliability. The portfolios in this case were examination script responses to "five legal questions derived from a case scenario, with their responses typically ranging from 3500 to 4000 words across nine pages" (Egelandsdal et al., 2025, p. 6). However, in this timeframe, the judges only completed between 36 and 70 comparisons each, with median times per comparison ranging from 3 to 41 minutes.

[1] Comparative judgement (CJ) differs from adaptive comparative judgement (ACJ) simply through the use of an "adaptive" algorithm in the latter to select which portfolios will be presented to judges for comparison. They do not differ in user experience of final rank modelling.

Overall, 393 comparisons were made of the estimated requirement of 1496 to 1800, i.e., approximately 20% to 25% of projected comparisons were made.

While this is not a good sign for the feasibility of ACJ, it is worth noting that the context for assessment is factor to consider. In the case of Egelandsdal et al. (2025), judges were comparing examination scripts of approximately 9 pages of text. This is not common for technology education assessment, where ACJ is proposed primarily for the assessment of student responses to design activity. Across two studies from technology education which have reported on the time taken to make comparisons (Bartholomew et al., 2018; Seery et al., 2019), the average reported time per comparison was just over 3 minutes, with average ranges from 55 to 206 seconds, markedly less than what was reported by Egelandsdal et al. (2025). Further, Jones and Davies (2024) caution that fatigue may effect time in situations where there are too many comparisons. An extension of this is the possibility of fatigue when comparisons are too difficult, where difficulty could relate to the amount of information to retain about individual pieces of work, or where the work is relatively close in quality it may be difficulty to determine which is better.

In response to this knowledge gap, and ongoing efforts to develop ACJ specifically in line with technology education needs, the study aims to investigate the time taken for assessors to make holistic binary comparisons of student work typical of technology education design activity. To add more nuance, the study has three objectives:

(1) To examine the average time taken for judges to make comparisons between portfolios of student work in technology education design activities,

(2) To explore whether there is a relationship between the time taken to make these comparisons and how difficult the comparison is to make, where difficulty is conceptualised as a measure of how close to each other the works are on the resulting rank, and

(3) To determine whether fatigue has a significant impact on time taken to make comparisons, where fatigue is considered to set in over time as comparisons are made.

METHOD

Approach and data

The aim of this study is to examine the prospective relationship between the time taken for a judge to make a holistic binary comparison between two portfolios of student work in an ACJ assessment session, and the apparent difficulty of the comparison to be made. To achieve this, the study involved a cohort of primary and secondary level pupils completing a design assignment, with a cohort of judges assessing their work in a CJ session. The pupils outputted their work at two stages – design ideation and prototyping – and separate CJ sessions were conducted for each. The output of one session was analysed in an exploratory manner and the other was used for confirmatory analysis. The CJ platform used was from No More Marking (2020), which provided data on the time taken for each comparison, and difficulty was defined based on the resulting rank

other, where the closer portfolios were to each other the more difficult the comparison was taken to be, and the further apart they were the easier.

Participants and setting

Twenty industrial designers were recruited as judges to assess the design work of 201 primary and secondary school pupils in the Netherlands. Five were recent master's graduates, while the remaining judges were current master's students in the Industrial Design Engineering department at Delft University of Technology. Twelve of the judges had prior academic or professional experience in designing for or with school-aged children. All judges took part in a 30-minute training session online that familiarised them with the nature of the design task, the assessment objectives, and the use of the comparative judgment platform.

Design task

The design task given to pupils was developed by the Science Hub at Delft University of Technology and has been used in design classrooms across several local schools. Based on a real-world problem – seagulls causing annoyance in beach areas in the Netherlands – the task challenged pupils to come up with a creative design that enables people to enjoy their fries on the beach without being disturbed by seagulls. Pupils were informed that their design should not harm seagulls and should be easy to use on the beach. Working individually, each pupil used an A3 foldable booklet to document their ideas and sketched solutions. The format of the booklet was inspired by design portfolios developed in the TERU project (Kimbell & Stables, 2007), which emphasised the iterative and reflective nature of the design process.

In the 40-minute design session, pupils were first prompted by the researchers to draft up to six different ideas. They were then prompted to think of an additional four ideas that could be even more uncommon and creative. Finally, each pupil selected their most original idea and developed it into a detailed prototype sketch with annotations about the features and intended functions of the design. Full details about the design task are available in (Zhu et al., 2025).

Implementation

Photographs of the pupils' brainstorming and prototype sketches were anonymised and uploaded to a free online comparative judgment platform, No More Marking (2020). Pupils' handwritten annotations were typed out for clarity if they were difficult to read. The brainstorming and prototype outputs were assessed separately. Judges first completed all judgments related to design prototypes (Figure 1) before proceeding to evaluate ideation sketches (Figure 2). This sequence was chosen to provide judges with a clearer understanding of pupils' design intent before evaluating the less detailed initial sketches.

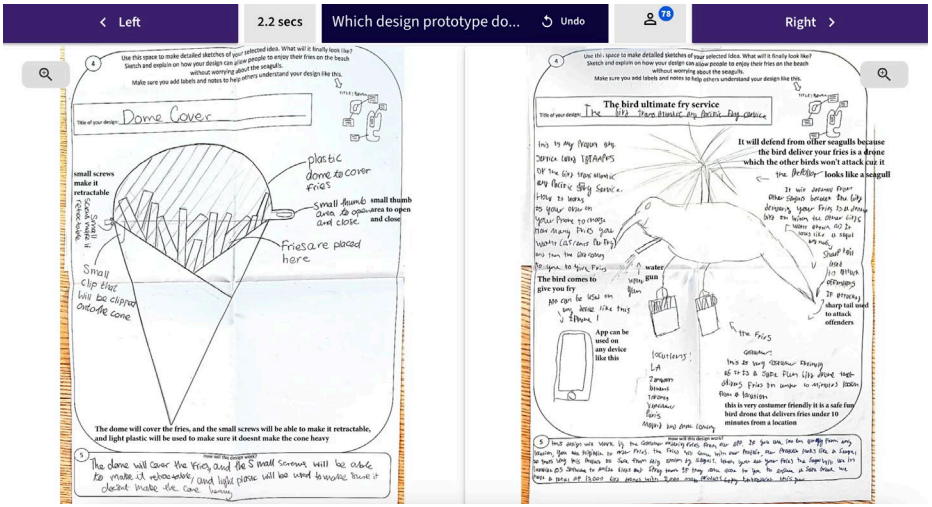

Figure 1. A pair of design prototypes presented for comparison on the comparative judgment interface.

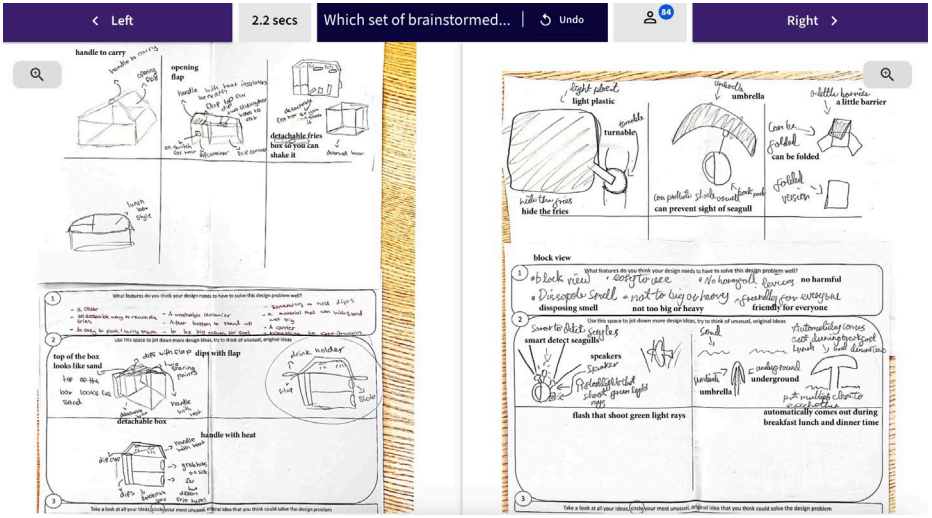

Figure 2. A pair of design ideation sketches presented for comparison on the comparative judgment interface.

Without set criteria, judges assessed creativity in pupils' work based on their personal or professional experience, choosing the more creative piece of work from pairs generated by the platform. Each judge completed 101 pairwise comparisons ([201 pieces of work × 10]/20 judges)

for both brainstorm sketches and prototype sketches. Judges were asked to leave comments on the first and the final 15 judgments they made and were encouraged to provide additional comments throughout the process if it helped clarify their reasoning behind each decision. A result of this was that in some cases, judges left more than the 30 requested comments, and in two cases (judge 7 for prototypes, and 17 for ideation), the judges left comments for each comparison. The platform automatically recorded the time spent on each judgment and whether a comment was provided for the decision.

Analysis

Initially, based on the outcomes of all pairwise comparisons within each session, ability scores for each portfolio were estimated using the BTL model using the btm() function in the sirt R package (Robitzsch, 2021). Comparisons where assessors left written comments were then removed from data to avoid inflating judgement time. Outliers in response time were identified as of Q1 − (1.5 × Interquartile range [IQR]) for the lower limit and Q3 + (1.5 × IQR) for the upper limit and removed to ensure timing data reflected active decision-making. For each pairwise comparison, a continuous measure of difficulty was then calculated based on the predicted win probability from the ability estimates, where comparisons between similarly ranked portfolios were considered more difficult.

The exploratory analysis was conducted with the comparisons made for the design ideation portfolios. To investigate whether difficulty and fatigue predicted judgement time, four models were estimated: a simple linear model, a linear mixed effects model (LMM) with random intercepts and slopes for each judge, a generalised additive model (GAM), and a generalised additive mixed model (GAMM) with judge-specific smooth terms. A simple linear model assumes a straight-line relationship between predictors and the outcome, with the same effect applying across all observations. An LMM extends this by allowing for random effects, such as different intercepts or slopes for each participant, thereby accounting for clustering or repeated measures. GAMs relax the assumption of linearity by fitting smooth curves, enabling the detection of non-linear relationships rather than assuming all effects follow a straight line. GAMMs combine these advantages, allowing non-linear relationships while also incorporating random effects to capture individual-level variation. This sequence of models represents a progression from simpler, more restrictive assumptions to more flexible approaches that can accommodate both non-linearity and heterogeneity across individuals. Model comparisons were conducted using AIC, explained variance (adjusted R^2, marginal and conditional R^2), and deviance explained as relevant. For the confirmatory analysis, based on the results of the exploratory analysis, two models were fit: a linear mixed effects model with random intercepts and slopes for each judge, and a GAMM with judge-specific smooth terms. In addition, to explore potential heterogeneity in pacing behaviour, separate linear and quadratic regressions were fit for each judge to characterise individual temporal trends.

RESULTS

Data cleaning and preparation

As noted, the ability scores were computed for each piece of work by fitting the Bradley-Terry-Luce model to the outcomes of each comparison using the btm() function in the sirt R package (Robitzsch, 2021), similar to the process used by Buckley (Buckley, 2024; Buckley & Canty, 2022; Buckley & Lin, 2024). This was done for both the ideation and prototype sessions, and the outcomes are shown in Figure 3.

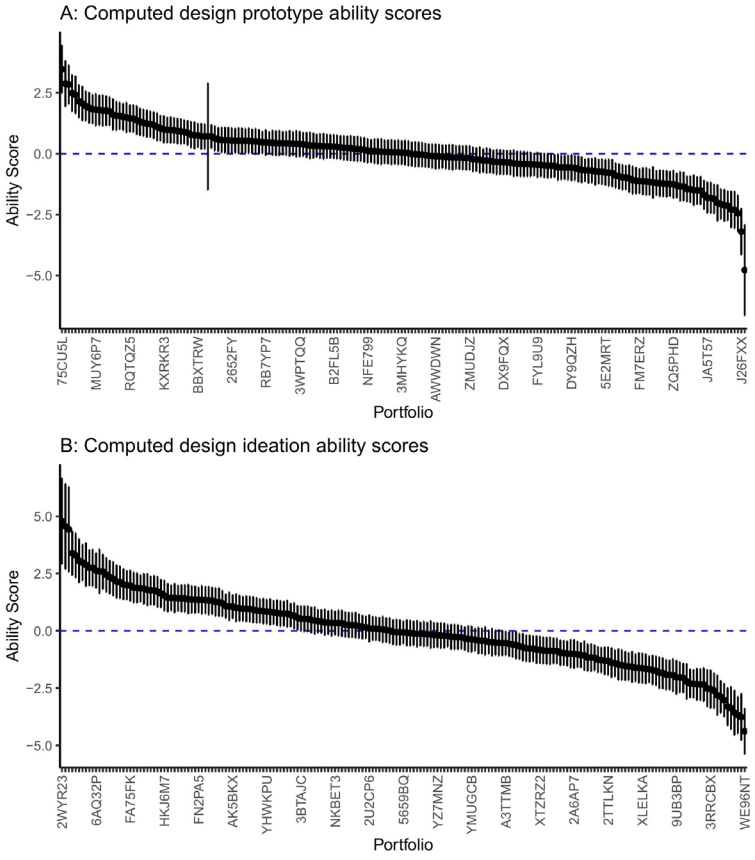

Figure 3. Estimated ability scores for design ideation and design prototype sketches. The SSR for the design ideation sketches was .834, and the SSR for the design prototype sketches was .735.

Next, the data were cleaned to remove comparisons where assessors left comments, as the process of leaving comments would add time to these judgements not specific to the judgements themselves. With these removed, there were 1266 comparisons for the ideation sketches and 1268 comparisons of the prototype sketches. Outliers were then identified and removed, with outliers being identified as any comparisons having time measured beyond the limits of (1.5 × IQR) – Q1 for the lower limit and (1.5 × IQR) + Q3 for the upper limit. For brainstorm there were 81 outliers beyond the upper limit, and for prototype there were 79 outliers beyond the upper limit. These were possibly cases were assessors, in the middle of a comparison, had to leave what they were doing but left their computer on.

Finally, as the study aimed to examine whether the difficulty of a comparison predicted the time taken to complete it, a measure of difficulty needed to be estimated. For this, the probability that the chosen portfolio *i* would be selected over the not chosen portfolio *j* was computed using the BTL model as

$$P_j(\alpha_i) = \frac{exp(\alpha_i - \alpha_j)}{1 + exp(\alpha_i - \alpha_j)} \quad 1$$

where α_i is the ability score of portfolio *i* and α_j is the ability score of portfolio *j*, where their ability scores were taken from the ACJ model (Figure 3). This "win probability" approaches 1 where the difference between x and y is large, and 0.5 with the portfolios are similar in computed ability.

To then create a continuous measure of difficulty, these probability values were then transformed such as higher values corresponded to more difficult comparisons (i.e., where portfolios were closely matched in ability). The transformation used was:

$$difficulty_{ij} = 1 - \left(2 \times \left|P_j(\alpha_i) - 0.5\right|\right) \quad 2$$

this function gives values close to 1 for difficulty comparisons, and close to 0 for easy comparisons. The resulting difficulty scores were used as a predictor of comparison time in the subsequent models.

Exploratory analysis

The mean time taken to complete a comparison in the ideation dataset, after removing outliers and comparisons with assessor comments, was $M = 50.77$ seconds ($SD = 44.40$).

Four models were fit to examine the potential relationship between difficulty and time taken per comparison. First, a simple linear model was estimated, which indicated no meaningful relationship between difficulty and time taken ($\beta = 4.92$, $SE = 4.26$, $p = .248$), with difficulty accounting for less than 0.2% of the variance in time taken (*adjusted* $R^2 = .0003$, $AIC = 12{,}356.44$). A LMM, which included random intercepts and slopes for each judge, provided a better fit to the data ($AIC = 11{,}896.66$), although the fixed effect of difficulty remained non-significant ($\beta = 5.84$, $SE = 4.22$, $p = 0.184$). The inclusion of random slopes indicated variability

between judges in how difficulty influenced their decision time, with a negative correlation observed between intercept and slope estimates (r = –.74). The fixed effect of difficulty alone accounted for 0.2% of the variance in judgement time (*marginal* R^2 = .002). When accounting for both the fixed and random effects, the model explained 36.4% of the variance in time taken (*conditional* R^2 = .364).

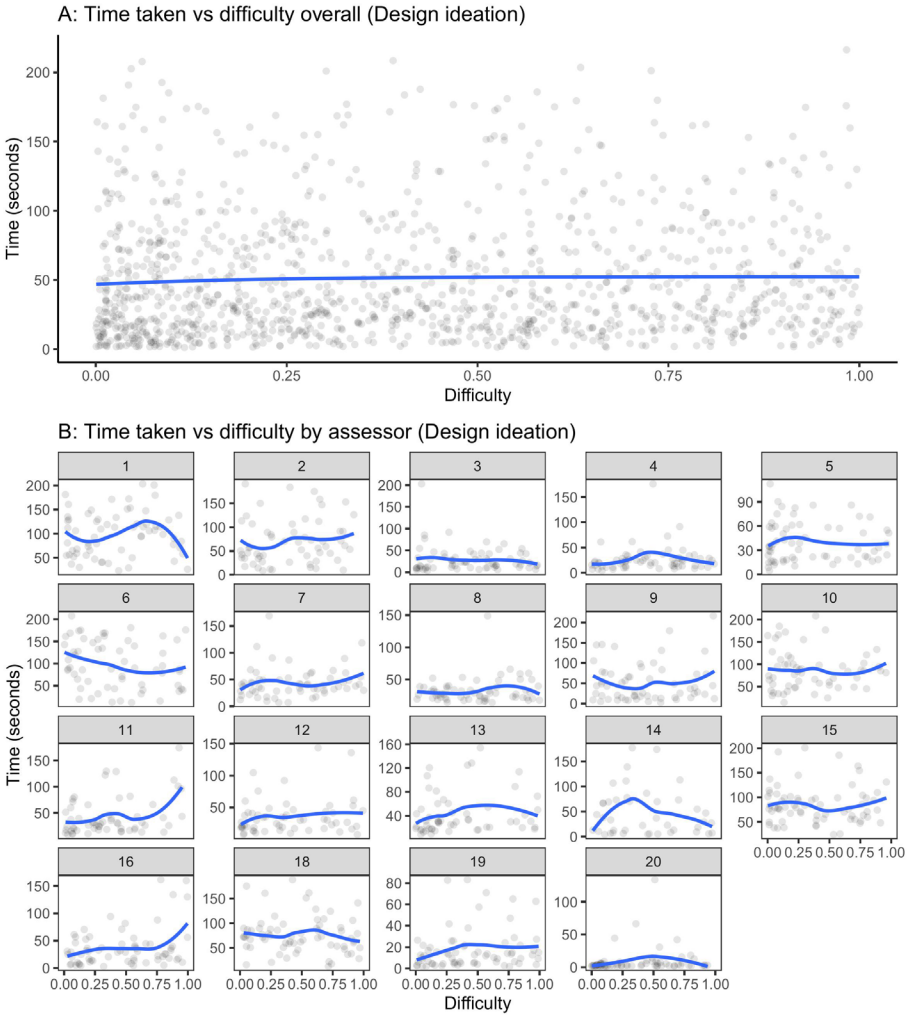

Figure 4. Relationships between time taken for comparisons and estimated difficulty, overall and for each assessor, for the design ideation data.

To explore the possibility of non-linear effects given the apparent patterns observed in Figure 4, a GAM and GAMM model were estimated. The first GAM model included a single smooth term for difficulty and provided no evidence of a non-linear relationship (*edf* = 1.00, *F* = 1.33, *p* = .248), with the smoother reducing to a linear form and offering no improvement over the simpler linear model (*AIC* = 12356.44). Difficulty accounted for just 0.1% of the variance in judgement time (*adjusted* R^2 = .0003), and the deviance explained was 0.11%. The GAMM model extended this by allowing the effect of difficulty to vary non-linearly across judges through a by-variable smooth, alongside random smooths for judge-level baselines. Model fit improved marginally (*AIC* = 12317.26), although the smooth term for judge-by-difficulty was not significant (*edf* = 2.00, *F* = 1.76, *p* = .172). Explained variance increased slightly (*adjusted* R^2 = .034), and deviance explained rose to 3.52%. While there was no evidence of a general non-linear relationship between difficulty and time taken, these models suggest that some assessors exhibited individual response patterns not shared across the group.

Four similar models were fit to examine whether judgement time changed over the course of the session, using judgement order as a proxy for fatigue. First, a simple linear model was estimated, which indicated no meaningful relationship between judgement order and time taken (β = 0.0049, *SE* = 0.0638, *p* = .939), with judgement order accounting for effectively none of the variance in time taken (*adjusted* R^2 = –.0008; *AIC* = 12,357.77). A LMM, which included random intercepts and slopes for each judge, provided a better fit to the data (*AIC* = 11,892.87), although the fixed effect of judgement order remained non-significant (β = 0.0140, *SE* = 0.0889, *p* = .877). The fixed effect accounted for virtually none of the variance in judgement time (*marginal* R^2 < .001), while the model as a whole explained 38.1% of the variance (*conditional* R^2 = .381).

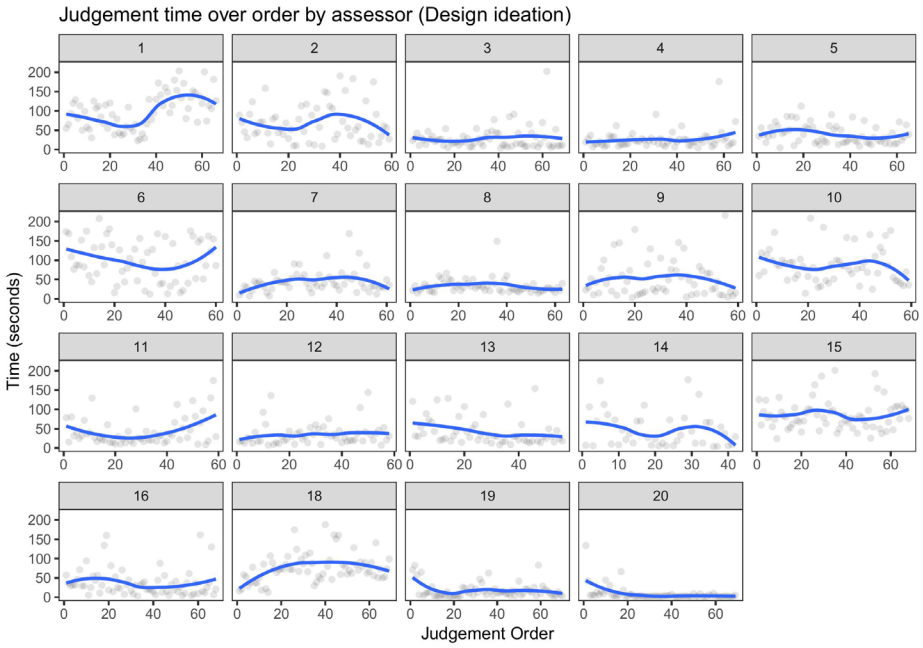

Figure 5. Relationships between time taken for comparisons and comparison order as a proxy for fatigue for each assessor, for the design ideation data.

To explore potential non-linear fatigue effects (see Figure 5), a GAM and GAMM model were estimated. The first included a single smooth term for judgement order, representing the non-linear equivalent of the simple linear model. The smoother reduced to a linear form (*edf* = 1.00, $F = 0.006$, $p = .939$), providing no improvement over the simpler linear model (*adjusted* $R^2 = -.0008$; deviance explained = 0.0005%; *AIC* = 12,357.77). A GAMM model allowed the effect of judgement order to vary non-linearly across judges via a by-variable smooth, alongside random smooths for judge-level baselines. Model fit improved (*AIC* = 12,318.91), although neither the judge-by-order smooth (*edf* = 2.00, $F = 0.92$, $p = .399$) nor the judge-level term (*edf* ≈ 0, $F = 0.00$, $p = .500$) were statistically significant. The model explained 3.39% of the variance in time taken (*adjusted* $R^2 = .0323$). Across all models, there was no evidence of a systematic group-level fatigue effect, though individual variation in judgement time was observed.

Confirmatory analysis

The mean time taken to complete a comparison in the ideation dataset, after removing outliers and comparisons with assessor comments, was $M = 49.83$ seconds ($SD = 37.84$).

To confirm whether the non-significant relationship between difficulty and judgement time observed in the design ideation dataset replicated in the prototype dataset, two models were

estimated. A LMM, which included random intercepts and slopes for each judge, indicated no significant fixed effect of difficulty (β = –0.66, SE = 3.67, p = .858), and the model accounted for no variance via the fixed effect (*marginal* R^2 = <.001; AIC = 11,781.25). A GAMM was also estimated, allowing for judge-specific smooths of difficulty and judge-level random intercepts. As in the linear mixed effects model, no evidence of a non-linear relationship between difficulty and judgement time was observed (edf = 8.51, F = 1.28, p = .233), and the judge-level term was non-significant (F = 0.00, p = .354). Model fit was lower relative to the linear mixed model (AIC = 11,994.54), and the model explained only 3.3% of the variance in judgement time (*adjusted* R^2 = .026). Together, these confirmatory analyses suggest no meaningful association between difficulty and time taken, consistent with the exploratory findings. The relationship between difficulty and time taken is illustrated in Figure 6 for the design prototype dataset.

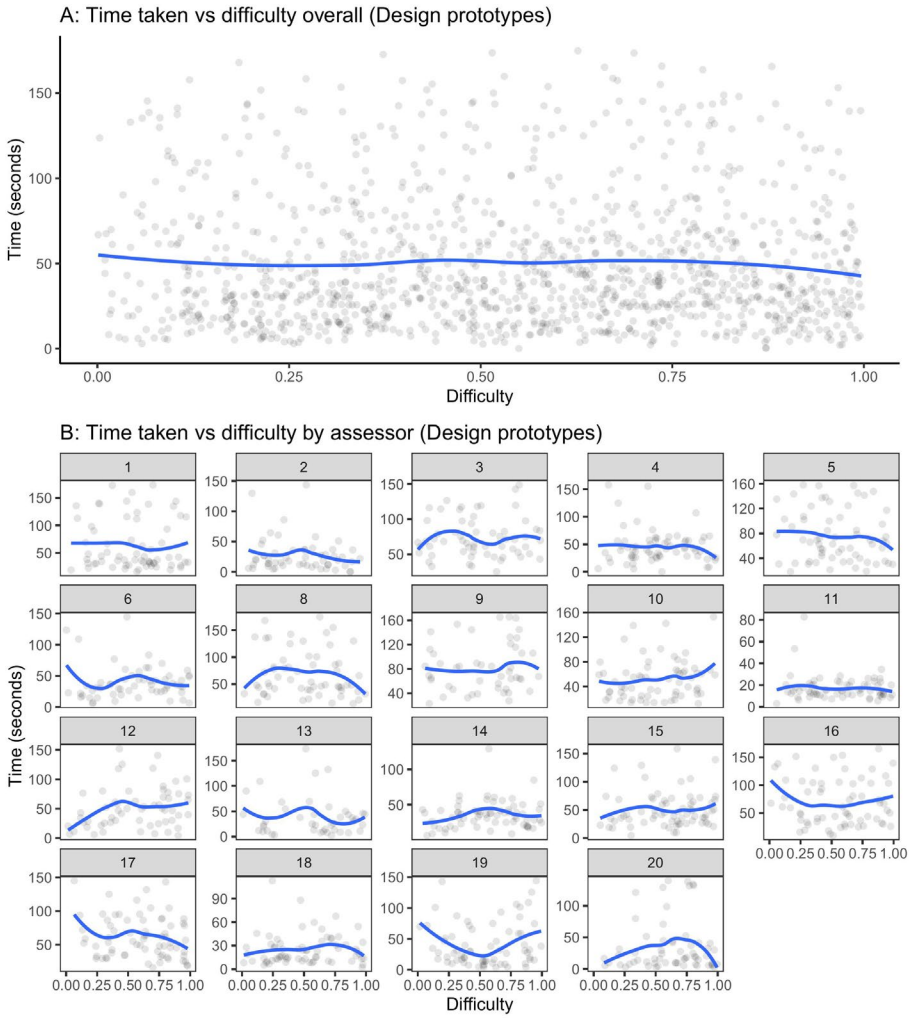

Figure 6. Relationships between time taken for comparisons and estimated difficulty, overall and for each assessor, for the design prototypes data.

To confirm whether judgement time changed over the course of the session, LMM and a GAMM were estimated using judgement order as a proxy for fatigue. The LMM, which included random intercepts and slopes for each judge, showed no significant fixed effect of judgement order (β = –0.14, SE = 0.15, p = .364). The fixed effect explained only 0.6% of the variance in time taken

(*marginal* R^2 = .006), although the model as a whole explained 35.2% of the variance (*conditional* R^2 = .352; *AIC* = 11,624.78).

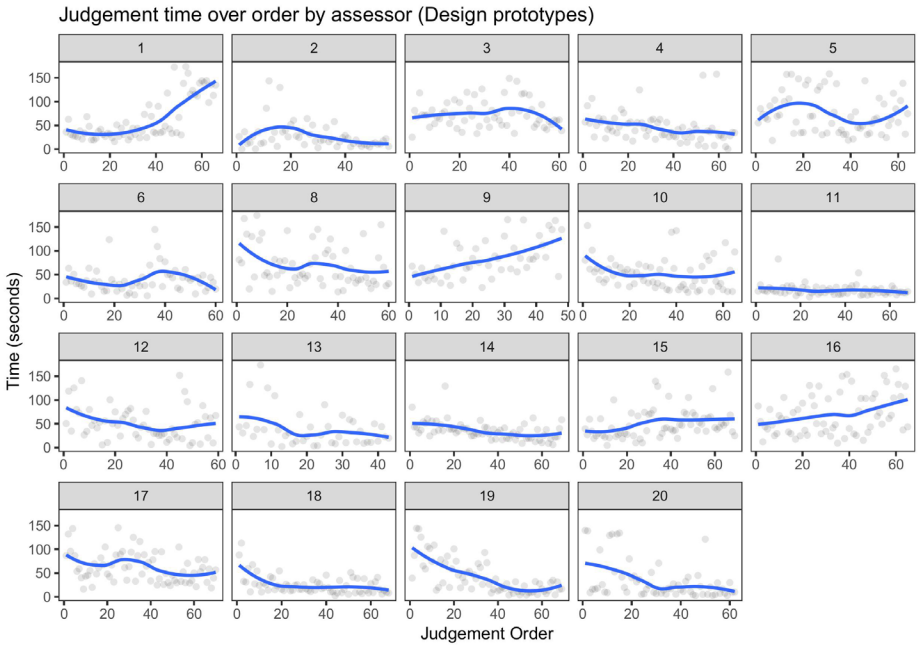

Figure 7. Relationships between time taken for comparisons and comparison order as a proxy for fatigue for each assessor, for the design prototypes data.

In contrast, the GAMM revealed a significant non-linear effect of judgement order at the individual level (*edf* = 2.65, F = 10.55, $p < .001$), suggesting some judges exhibited temporal patterns in judgement time consistent with potential fatigue or strategy shifts. The judge-level smooth was also statistically significant (F = 0.00, $p < .001$), although the extremely small effective degrees of freedom (*edf* ≈ 0) suggest this term primarily functioned as a penalised intercept. The model explained 4.5% of the variance in time taken (*adjusted* R^2 = .0431; deviance explained = 4.52%) with a higher AIC value than the LMM (*AIC* = 11,967.68). These results contrast with the exploratory findings, where no judge-specific non-linear effects were observed, and suggest that in the prototype dataset, some assessors may have exhibited individual fatigue or pacing effects over the course of the session.

To examine this further, judgement time was modelled separately for each judge using both quadratic and then linear regression. Quadratic modelling identified five judges with significant non-linear trajectories: Judges 1, 18, and 19 showed U-shaped curves, and Judges 2 and 3 an inverted-U pattern. Beyond these, three judges showed significant positive linear slopes, indicating increased time taken across the session (Judges 9, 15, and 16), while six showed

significant negative slopes, suggestive of increasing efficiency or disengagement (Judges 4, 8, 13, 14, 17, and 20). The remaining judges exhibited no statistically significant quadratic or linear trends. Notably, visual inspection of time–order plots (Figure 7) revealed further complexities in pacing behaviour, such as oscillating or wave-like patterns (e.g., Judge 5), that were not well captured by the models, reinforcing the value of flexible smoothing approaches in ACJ timing analysis.

DISCUSSION

This study investigated the time taken for judges to make holistic binary comparisons in ACJ assessment of student design work in a technology education context, with a particular focus on whether comparison difficulty or judge fatigue influenced judgment time. Average times taken to make comparisons were approximately 50 seconds, which is lower than observed by Seery et al. (2019) and at the lower end of observations from Bartholomew et al. (2018). Taken together through a weighted average, these three studies suggest that ACJ comparisons in technology education contexts take $M_{weighted}$ = 154.94 seconds or 2.58 minutes ($SD_{weighted}$ 177.90 seconds or 2.97 minutes).

Across both exploratory (design ideation) and confirmatory (design prototype) analyses, there was no consistent evidence that more difficult comparisons required more time to complete. Similarly, no systematic group-level fatigue effects were found, though some individual judges exhibited idiosyncratic temporal patterns, including both accelerating and decelerating trends over time.

These findings carry important practical implications for the implementation of ACJ in technology education contexts. First, they suggest that time per judgment is relatively stable, regardless of comparison difficulty or cumulative fatigue, at least within the bounds of the design tasks and judgment volumes studied here. This means that future attempts to enhance the feasibility and scalability of ACJ in technology educational settings may not need to account for differential timing across comparisons due to these factors. Instead, efforts to improve efficiency seem more effectively targeted at the algorithmic level. For instance, through optimisation of portfolio pairing strategies to reduce the total number of comparisons required for reliable ranking (cf. Buckley & Lin, 2024). This is especially relevant in light of broader efforts to develop open-access ACJ tools (Buckley, 2024) for classroom use, where time constraints are a key concern.

From a theoretical standpoint, the observed stability of judgment time across varying levels of difficulty suggests that assessors may not be engaging in slow, effortful deliberation, but rather using simple decision strategies or heuristics. This opens up further questions related to decision making heuristics and system 1 and system 2 thinking (Kahneman, 2011). In particular, the absence of longer deliberation for more difficult comparisons implies that judgments in ACJ may be guided by fast, frugal cues such as salient visual features, intuitive impressions, or rapidly accessible priors about design quality, rather than systematic analysis of closely matched portfolios. This interpretation aligns with research on heuristic decision-making, which demonstrates that people frequently rely on cognitively efficient strategies when faced with uncertainty, complexity, or time constraints (cf. Gigerenzer & Gaissmaier, 2011).

ACJ, as a judgment format, may thus offer an environment for bridging educational assessment with theories of bounded ecological rationality (Gigerenzer & Goldstein, 1996; Goldstein & Gigerenzer, 2002). Rather than viewing variability in judge decisions as noise, future research could investigate whether judges adapt their decision strategies to task structure and information affordances. This opens a novel line of inquiry for ACJ studies: to model and empirically test the specific heuristics employed by judges, how these interact with task features (e.g., visual complexity, design familiarity), and whether such strategies vary systematically by expertise or training. In this way, ACJ may not only benefit from cognitive theory but also contribute to it, by offering rich, ecologically valid data on comparative human judgment in open-ended domains.

Finally, while these results are promising for future work to improve the feasibility of ACJ in technology education, they should be interpreted cautiously. The findings are based on a specific task and sample, and replication in additional studies with varied design contexts, age groups, and judgment volumes is necessary to confirm their generalisability. Future research might also explore whether similar time stability holds when judges assess more complex or unfamiliar forms of student output, or when working under different instructional framings.

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Education and Energy Transition: Challenges of Introducing Renewable Energies into Secondary Education in Tunisia

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Abstract

Climate change is one of the greatest challenges of our time, which, according to institutional and political discourse, requires an imperative ecological and social transition (AFD, 2021). Therefore, it is crucial to prepare citizens for these new environmental challenges by equipping them with the skills needed to build a sustainable future. Technology education constitutes a strategic level of action, among others, to achieve this goal. In Tunisia, this dynamic is reflected in education, particularly through the introduction of renewable energy into the curriculum of the third year of technical sciences in high schools, with a particular focus on solar energy from 2022. This initiative aims to train a generation of citizens aware of environmental issues and equip them with the skills necessary to actively participate in the energy transition (Technology Curriculum, 2022). Our study focused on analyzing teachers' practices in response to this educational reform. Through an analysis of the Tunisian curriculum and the activities offered to students, as well as a semi-structured interview with 10 teachers, we qualitatively explored how educational tools are used to raise student awareness of environmental issues. The results reveal several challenges, including the lack of internet access in classrooms, forcing some teachers to simplify or circumvent planned digital activities, such as the use of PV6 software. This problem limits students' acquisition of targeted photovoltaic simulation skills. Furthermore, teachers emphasized that the complexity of the calculations related to the sizing of photovoltaic installations, presented in the textbook, is often unsuitable for students' level, distancing them from the educational objectives related to autonomy and engagement in the energy transition. These results highlight the importance of rethinking the integration of educational tools within an accessible framework aligned with local socioeconomic realities, in order to strengthen the role of education in the ecological and social transition.

Key Words: Ecological transition, Solar energy, Teacher practices, Smartphone

1. CONTEXT OF THE STUDY

Renewable energy education has become a major issue in the face of new climate challenges. Renewable energies, such as wind, solar, hydroelectric, biomass, and geothermal energy, are considered environmentally friendly solutions for reducing dependence on fossil fuels and greenhouse gas emissions. The objective of this education is to raise awareness among new generations, develop technical and practical skills, and promote an understanding of social, economic, and environmental issues.

This trend of strengthening the theme of renewable energy in secondary school curricula by integrating energy-related topics into science and technology subjects is not specific to Tunisia. (Vince & Tiberghien, 2012) point out that energy education is often approached primarily through the lens of physics but lacks a coherent interdisciplinary approach that could enrich understanding of the socioeconomic issues of renewable energy. Dubois (2024) examines the implementation of these energies in France and identifies structural obstacles such as regional planning and societal resistance. The author highlights the importance of raising awareness among young people from the early stages of schooling. Furthermore, Poize and Rüdinger (2014) compare citizen renewable energy projects in France and Germany, indicating that education is crucial to foster social acceptance of energy projects. Challenges include a lack of teacher training on renewable energies and a lack of a systemic approach in school curricula. Similarly, Christen and Hamman (2015), who explore participatory projects in Alsace, demonstrate that citizen participation, supported by early education, is essential to support the energy transition.

In Tunisia, renewable energy education has been integrated into technology curricula from the 7th grade (age 12) to the 3rd year of secondary school (age 17). The curricula provide for a progression of knowledge, beginning with the implementation of renewable energies, their types, and their uses. Then, in this final stage, in the 3rd year of technical sciences, students delve deeper into the study of complete photovoltaic panel installation. However, during this stage, teachers focus on teaching scientific concepts at the expense of raising awareness of the importance of new, environmentally friendly sources of electricity.

This paper explores on the one hand, the ways in which renewable energy education has been integrated into Tunisian curricula, highlighting the pedagogical approaches adopted. On the other hand, it assesses students' understanding of renewable energy concepts.

2. QUESTIONING THE RELATIONSHIP BETWEEN ENERGY AND SOCIAL TRANSITION

It is important to emphasize that the Tunisian curriculum's choice to focus on energy is not insignificant. The theme of energy is, in fact, central when it comes to debating or raising awareness in society about ways to propose technical development while respecting environmental constraints. "*Energy is what links natural systems […] and social systems. Energy is the way in which social metabolism fits into natural metabolism*" (Sabot &Larrère, 2022, p. 63). It is therefore a relevant theme for initiating thinking about environmental and social transition.

The approach developed here is in line with the curriculum's teaching approach, which favors a critical perspective. It consists of questioning the purposes, strategy and didactic developments that structure the curriculum without "naturalizing" the technocratic rationality that could underlie them (Lange & Martinand, 2010; Zaid, 2017). This rationality often consists of assuming 1) that the advent of so-called renewable energies constitutes a new energy era, the product of a transition from coal and fossil fuels, which is historically false (Fressoz, 2019). This rationality also assumes that 2) the essence of social transition consists of developing new technical solutions adopting renewable energies. How then does the new Tunisian curriculum respond to the integration of the issue of sustainability and how does it relate to these two assumptions? In what ways do curricular choices translate into teaching practices in the classroom?

Different models can be used to analyze how sustainability is integrated into a curriculum. One example is the aforementioned curricular model used by Martinand to analyze education for sustainable development in French schools (Martinand, 2010). Colmos et al. (2016) propose another model for analyzing curriculum response strategies for integrating sustainability. However, in this exploratory study, the CIPP (Context, Inputs, Processes, Products) model proposed by Imansari (2017) will be used, which aims to analyze how the ecological transition is integrated into a curriculum.

3. METHODOLOGY

To analyze the integration of renewable energy into the Tunisian education system, this research focuses on the third-year curriculum in technical sciences, specializing in electrical engineering, designed for students aged approximately 17. The analysis is based on Imansari's (2017) CIPP (Context, Inputs, Processes, Products) model, which allows for a structured assessment of how the ecological transition is integrated into this program, taking into account contextual dimensions, teaching resources, teaching practices and expected outcomes. In addition, to enrich this study, interviews comprising 15 targeted questions were conducted with 10 teachers specializing in this subject. These interviews aim to explore in depth how these teachers perceive, adapt and transmit the importance of the ecological transition, highlighting their teaching strategies, the challenges encountered and their ability to raise students' awareness of the environmental and societal issues related to renewable energies.

4. RESULTS AND DISCUSSION

4.1. Curriculum Analysis

Table 1 below explores the disciplinary skills for the "renewable energy" theme in the third year of technical sciences, specializing in electrical engineering. We note that there is no explicit mention directly related to the ecological transition.

Table 1.
Targeted disciplinary skills for teaching renewable energy

Disciplinary Competencies

3rd year secondary (Electrical Engineering)	**CD1.2:** Determine the characteristics of an electrical machine or an electrical assembly. **CD2.2:** Implement an electrical machine or an electrical assembly and analyze the electrical or mechanical quantities involved. **CD3.2:** Describe an electrical machine or an electrical assembly and provide an account. **CD1.1:** Initiate knowledge of electrical safety rules. **CD2.1:** Apply electrical safety rules. **CD3.1:** Read and interpret diagrams and symbols related to electrical safety and provide an account.

The skills mentioned are primarily disciplinary and technical (see Appendix 1). They focus on electrical safety, determining the characteristics of an electrical machine, and analyzing electrical quantities. There are no terms or direct references to the ecological transition or environmental issues. To further refine our analysis, we use the CIPP grid (Imansari, 2017), as shown in Table 2.

Table 2.
CIPP Grid for Curriculum Assessment

Category	Evaluation Criteria	Indicators/Questions	Data Collected
Context	Relevance of objectives in relation to societal, professional, or educational needs	- Which needs justify this curriculum? - Do the objectives meet these needs?	Reports, surveys, sectoral analyses
Input (Resources)	Adequacy of material, human, and pedagogical resources	- Are financial, material, and human resources sufficient? - Are pedagogical resources up-to-date and adapted?	Inventory of resources, budgets, descriptions of outputs
Process	Effectiveness of pedagogical methods and their implementation	- Do the methods promote student engagement? - Are activities aligned with the objectives?	Observations, lesson plans, teacher feedback
Product	Results and impact of the curriculum on learners' competencies	- Do evaluation criteria measure competencies effectively? - Is there a high level of satisfaction?	Evaluation results, statistics, satisfaction surveys

This model examines four dimensions: context (relevance of objectives and fit with market needs), inputs (curriculum structure, resources and equipment, and teacher profiles), process (teaching methods, integration of assessment, and the theory-practice link), and outputs (skills acquisition, assessment of prior learning, and job preparation). Table 3 illustrates the analysis according to the CIPP.

Table 3.
CIPP Curriculum Analysis Grid

Dimension CIPP	Curriculum Analysis	Limits and Possible Improvements
Context	- Objectives aligned with the real needs of the energy sector (energy transition,	- Absence of a preliminary analysis of local market needs.

	ecological, electrical safety, energy efficiency). - Concrete problems (e.g., dimensioning of solar installations). - Competencies clearly defined (CD1.2, CD2.2, etc.).	- Absence of verification of prerequisite knowledge.
Inputs	- Resources technically mentioned in detail (apparatuses of measurement, logical PVSyst, electrical components). - Knowledge and know-how well identified (definitions, calculations, safety notions, dimensioning of photovoltaic installations). - Clear pedagogical structure (sequences triggering learning → evaluation). - Availability of material resources such as measurement apparatuses, PV panels, smartphones, and internet connection.	- Underutilization of resources mentioned in the curriculum, such as the logical PVSyst. - The training of teachers is not addressed.
Process	- Pedagogical approach with a triggering situation, practical group work, measures, resolution of problems, manipulation, communication. - Logical progression between theory and practice (basic then complex applications). - Education on safety included in all stages. - Integrated evaluations (oscillograms, syntheses).	- Technical calculations lack guidance, risking cognitive overload. - Methods could be more diversified, with a lack of role-playing in case studies. - Electrical safety is overly theoretical.
Products	- Mastery and acquisition of competencies (calculations, dimensioning PV, security). - Analysis, dimensioning professionalism (norms following STEG, choice criteria). - Concrete productions (elaboration of reports, realization of projects). - Evaluation criteria selected based on required competencies (choice of devices, problem-solving, collaboration, respect of safety norms).	- Lack of an impact measure; absence of indicators of effectiveness. - Competencies transversally neglected, such as innovation and durability. - Limited adaptability due to lack of choice. - Technological evolutions are not anticipated.

This grid clearly demonstrates the clarity of the objectives and the targeted skills. We clearly note the integration of contemporary issues, such as the energy transition. The methodology adopted is active and contextualized. Furthermore, the assessment criteria are precise and very well aligned with professional skills. However, this curriculum is dependent on specific material resources, which limits equity of access. We also note that no information is provided on continuing teacher training.

The program, although focused on advanced technical content, appears not to truly adapt to diverse learner profiles, particularly those with specific educational needs or varied learning

styles. The method remains highly standardized and technical, without explicitly incorporating differentiated teaching strategies that would promote the full inclusion of all students, regardless of their initial level or learning problems. Furthermore, it is deplorable to note the absence of activities encouraging collaboration and interdisciplinarity at a time when these skills are essential for success in the professional world.

Another important point is that the assessment aspect seems primarily focused on quantifiable technical skills, whereas the inclusion of formative and self-assessment would promote learner independence and accountability.

4.2. Positioning the program in relation to the two assumptions

The idea that renewable energies mark a new energy era is reflected by the inclusion of photovoltaic installations (CD2.1, CD3.1). However, this technical approach does not challenge the historicity highlighted by Fressoz (2019), suggesting continuity with fossil fuels. Indeed, the Tunisian program adopts a pragmatic and educational approach by integrating photovoltaic energy as one technical component among others, without presenting this transition as a linear or "natural" historical rupture. The module includes the sizing of a photovoltaic installation connected to the STEG grid, which demonstrates a desire to integrate renewable energies with the existing (mixed) energy system, rather than pitting them against each other. Furthermore, the emphasis is placed on technical calculations (power, energy consumption) and practical implementation, thus avoiding an idealized discourse on renewable energies. However, the program has limitations, including its lack of explicit consideration of energy history (as Fressoz, 2019, points out) or the continuities between fossil and renewable systems. This reinforces the need for a critical perspective on socio-technical challenges (intermittency, costs, etc.).

The emphasis on technical skills (power calculations, installation implementation, CD2.1, CD3.1) prioritizes technical solutions over societal analysis, as proposed by Sabot and Larrère (2022). However, safety and life skills open the door to critical teaching. The Tunisian curriculum demonstrates a desire to balance technical skills and awareness of societal issues but remains focused on technological solutions. Its strengths center around safety education and communication, which are integrated as transversal skills, emphasizing the importance of social dimensions (e.g., use of prevention signs). Similarly, the electricity bill serves as a tool to link individual consumption and technical solutions (photovoltaic), introducing a reflection on behaviors.

However, the "environmental constraints" mentioned in the quote from Sabot and Larrère (2022) are not explicitly addressed in the knowledge (e.g., ecological impacts of energy production/consumption). As a result, the curriculum could better integrate technical and social transitions (e.g., debates on the acceptability of renewable energy, inequalities in access to energy). Small-group activities such as measurements, photovoltaic projects, etc., promote concrete learning, but could include critical case studies (e.g., the limitations of photovoltaics in Tunisia).

Our analysis using the CIPP model (Imansari, 2017) shows that the curriculum only partially addresses sustainability issues, emphasizing technical aspects rather than societal dimensions.

The building blocks, focused on photovoltaics, primarily promote technical efficiency. Although active pedagogy is an asset in the educational process, it lacks critical frameworks such as discussions. Furthermore, the outcomes, which focus on technical skills, do not indicate systemic awareness. In conclusion, the Tunisian curriculum manages to partially avoid a "technocratic rationality" by integrating renewable energies into quantifiable and secure practices, but it naturalizes their use without questioning their historical or social limits. To develop a critical approach, it would be wise to include historical elements concerning energy transitions, to encourage debates on technical choices (for example: centralized versus decentralized), and to explicitly link technical solutions to social justice (such as access to energy). This would allow for the evolution of a curriculum where sustainability appears more as a technical requirement than as a societal project with multiple dimensions.

4.3. Activity Analysis

Table 4 illustrates the photovoltaic section activities presented in the activity manual for the third-year technical sciences major, specializing in electrical engineering. These activities cover three main areas: single-phase alternating current, electrical safety, and renewable energies. This theme focuses on renewable energies, particularly through problem-solving and project-based learning activities related to photovoltaic energy and electrical grids. This will help students become aware of current energy issues and the need to develop and create sustainable solutions. Furthermore, activities focusing on measuring electrical power, calculating power factors, and various circuit losses help students understand the importance of energy efficiency, which is a key issue and a central challenge of the ecological transition. Furthermore, integrating concepts of electrical safety prepares students to adopt responsible behaviors and practices, which are essential in the management of renewable energy installations.

Activities are structured around problem-solving situations, hands-on exercises, small-group work, and projects. This method promotes cooperation and the development of various transversal skills such as analysis, communication, synthesis, etc. In addition, teaching resources include diagrams, measuring instruments, videos, and activity support links, allowing for a variety of learning styles and making concepts more understandable and accessible. In this new curriculum, new guidelines have been communicated to teachers. They are no longer authorized to distribute printed teaching materials. All essential tools are accessible via a QR code that students must scan to access them. Another important point is that the integration of assessment activities throughout lessons provides students with the opportunity to self-assess and gradually strengthen their knowledge. The proposed situations are directly inspired by real-life problems.

Table 4.
Activities proposed in the activity manual

List of Activities	
3rd year secondary (Electrical Engineering)	**Theme 1-1: Single-Phase Electric Current** Activity 1: Lighting problem Activity 2: Electrical quantities Activity 3: Electrical powers Abstract **Theme 1-2: Electrical Safety** Activity 1: Electrical hazards

Activity 2: Earth connection
Abstract
Theme 1-3: Renewable Energies
Activity 1: Choice of photovoltaic
Activity 2: Photovoltaic panels (QR code containing a link to aid for the activity)
Activity 3: PV installation connected to the STEG network (QR code containing a link to aid for the activity)
Activity 4: Choice of technology (QR code containing a link to aid for the activity)
Abstract

The integration of renewable energies is supposed to prepare students for the jobs of tomorrow and to understand the challenges related to the energy transition. However, we observe a lack of in-depth study of the overall ecological impact, due to a significant lack of analysis of ecological effects (life cycle, recycling, carbon footprint of devices). Although active learning is present, innovations remain focused on solving traditional problems and the use of standard devices such as computers with office applications.

Regarding assessment activities, these seem primarily focused on memorizing knowledge and taking measurements, to the detriment of assessing more complex skills (such as teamwork, critical thinking, and the ability to generate innovative solutions). However, some activities require specific equipment (transformers, oscilloscopes, etc.) that is not available in all schools, thus limiting equity of access.

4.4. Questionnaire Analysis

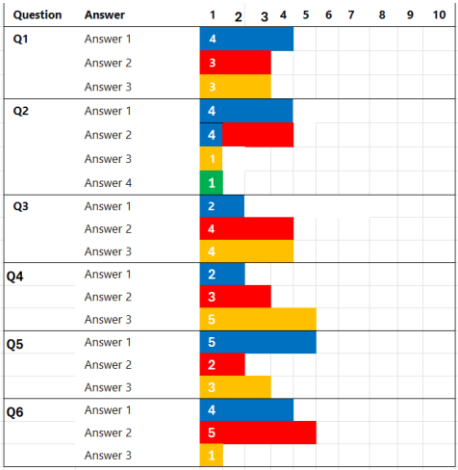
To evaluate the photovoltaic energy teaching module, the teaching methods, the tools used, the challenges encountered, and the prospects for improvement, we asked 15 questions to 10 teachers in the subject (see Appendix 2). The teachers were not rigorously selected. We asked ten teachers to voluntarily participate in this online questionnaire. This request was shared through a social media group. This approach highlights teachers' motivation to participate, as well as their use of technology as a communication tool. The attached table presents the teachers' demographic characteristics:

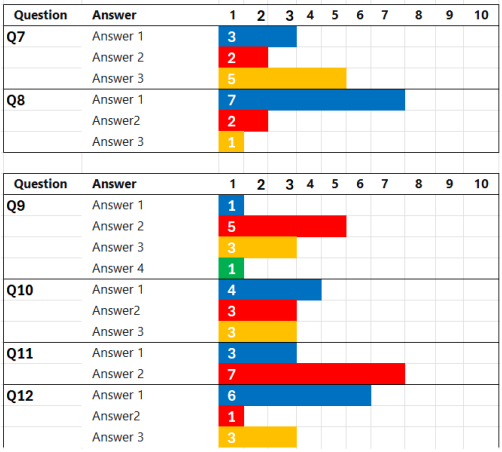
Table 5.
the teachers' demographic characteristics

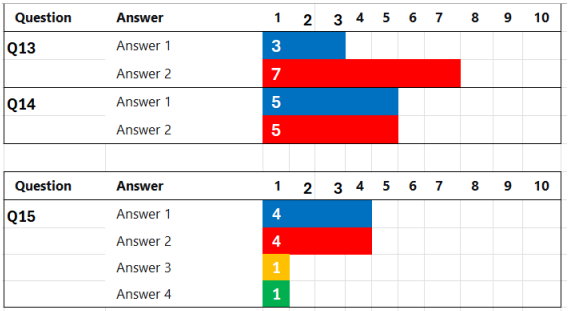
Teacher	Age	Gender	Seniority	Education Level	Region
E1	45 years	man	16 years	Mastery	Kasserine
E2	49 years	man	20 years	Mastery	Sfax
E3	35 years	Man	10 years	Doctor	Kairouan
E4	53 years	Man	26 years	Mastery	Sidi Bouzid
E5	29 years	Women	5 years	Master's degree	Manouba
E6	50 years	Man	21 years	Mastery	Monastir
E7	42 years	Man	15 years	Mastery	Manouba
E8	50 years	Man	20 years	Mastery	Sidi Bouzid
E9	41 years	Women	16 years	Doctor	Tunis
E10	48 years	Man	18 years	Mastery	Tunis

We addressed the teachers' pedagogical practices, the major obstacles encountered when teaching this module, the use of digital technology in the classroom, student engagement, and suggestions for improvement.

Figure 1.
Distribution of questionnaire responses







According to the teachers, the introduction of the renewable energy module highlights a trend toward traditional methods, with four teachers favoring theoretical explanations of electricity concepts, while only three offer practical experience, indicating limited practical grounding from the outset. Regarding the mastery and understanding of concepts, there is a strong use of active methods: four teachers create electrical assemblies using available materials, and four teachers use simulations. However, the use of videos remains marginal, with only one teacher using them. Regarding assessment, the most dominant practice remains the correction of individual exercises (4 teachers), which demonstrates a preference for summative assessment. Only two teachers diversify their approaches by adding quizzes or diagrams, highlighting a lack of variety in the assessment tools used.

The major obstacle identified to practical implementation is the lack of materials, mentioned by seven teachers. Another difficulty, although less significant, is also noted: the lack of student motivation (1 teacher). These results highlight a pressing need to invest in specific equipment, such as measuring instruments, to promote effective and stimulating practical application of learning.

The incorporation of digital technology in the classroom, based on the responses to questions 9 and 11 to 13, reveals several trends. Teachers consider simulation software (5 teachers) to be the most useful tool, appearing as an alternative to the lack of materials. Then, tools for creating presentations (3 teachers) are widely used compared to interactive online platforms (1 teacher), which indicate a use more focused on creativity than on real interaction with digital technology. However, the effective and optimal use of these tools is hampered by a significant obstacle: 7 teachers in the high schools concerned do not have Internet access, which considerably limits the resources available online. In line with this situation, a large majority (7 teachers) of teachers choose to favor paper course documents over digital content, which shows a pragmatic adaptation to the technical difficulties encountered on a daily basis.

Student engagement, assessed through questions Q5, Q6, and Q14, reveals limited use of available teaching tools. Although five teachers report offering online resources, only two actually implement active differentiation, such as creating groups based on grade levels, indicating an opportunity for improvement to adapt content to student needs. Regarding participation, five teachers encourage teamwork, demonstrating a desire to foster a collaborative teaching approach. Furthermore, four teachers organize classroom discussions, helping students become aware of contemporary social issues. Finally, although half of the teachers believe that all their students have access to a smartphone, this tool remains underutilized: only 6 teachers use QR code, suggesting a digital potential that remains to be fully exploited.

The areas for improvement identified through questions Q10 and Q15 highlight several wishes expressed by the participants. A significant proportion of teachers called for increased practical activities (4 teachers), indicating a strong demand for implementation, despite limitations related to equipment. Furthermore, three teachers recommended more teamwork and formative assessment, revealing significant interest in a more dynamic and cooperative teaching approach. Furthermore, two teachers made recommendations regarding reducing the length of calculations or compensating for the lack of equipment, aimed at reducing both cognitive and logistical burdens.

5. CONCLUSION

In this paper, we analyzed the teaching of the renewable energy module in Tunisia for third-year technical science classes. Indeed, the curriculum contains no guidance on raising awareness of the challenges of using photovoltaic energy. We observed that these activities incorporate an interdisciplinary approach. They combine physics, technology, and environmental issues. This consequently provides a comprehensive and contextualized view of knowledge. Similarly, the development of practical skills through manipulation, measurements, and diagram decoding allows for a transition from theory to practice. However, the activities include the use of PVsys software, which requires an internet connection to use. Similarly, for activity aids, activating the

links requires an internet connection. This presents a barrier for most Tunisian high schools. Teachers also noted that not all students carry smartphones. The same is true for activity resources: activating the links also requires online access. This presents a barrier for most Tunisian high schools. Teachers also noted that not all students have smartphones.

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Appendix 1: Translation of the curriculum for the third year of secondary school in Tunisia. Theme 1: Renewable Energy

Single-phase Electrical Network			**3rd Year Technical Sciences**	**Allocated Time: 12h**
Components of disciplinary skills	**Knowledge and Know-How**	**Life Skills and Citizenship Education ...**	**Orientations and/or activities**	**Evaluation criteria**
CD1.2: Determine the characteristics of a machine or an electrical setup. **CD2.2**: Operate a machine or an electrical setup and analyze the electrical or mechanical quantities involved. **CD3.2**: Describe a machine or electrical setup using complete and precise terminology **CD1.1**: Become familiar with electrical safety rules. **CD2.1**: Apply electrical safety rules. **CD1.6**: Decode technical documents related to electrical safety and energy.	**Single-phase electrical network** - Definition - Quantities and characteristics - Powers P, Q, and S and power factors - Renewable energies • Different sources • Calculation and sizing of a photovoltaic installation connected to the STEG network - Installation of assemblies enabling the measurement of electrical quantities in low-voltage (LV) systems. **Electrical safety** - Dangers of electric current - Prevention measures - Equipment	- Problem solving - Communication - Citizenship education - Safety	- Using a triggering situation involving the use of a local electrical network, adopt an appropriate teaching approach that allows the learner to: - Discover and acquire knowledge relating to the single-phase network. - Acquire knowledge about electrical hazards and electrical protection devices. In small groups: - Measure the electrical values of various single-phase loads such as single-phase motors, lamps, electric heaters, etc. - Measure the active power P, calculate Q and S, and represent the power triangle on a suitable scale. - Choose and use electrical prevention panels for the technology laboratory or for a photovoltaic installation. - Using an electricity bill, determine the electrical energy consumed to size a photovoltaic installation. - Calculate the electrical quantities related to an installation powered by a photovoltaic energy source. - Implement a photovoltaic installation. Communicate the results of the work in plenary session.	- Proper use and selection of electrical measuring devices. - Correct problem solving. - Active cooperation. - Full compliance with communication rules. - Proper implementation of the photovoltaic installation, with full compliance with electrical safety requirements.

Appendix 2: The questionnaire

1. When introducing the module, what tasks did you mainly perform?

A. Explain the basic concepts of electricity
B. Present the challenges related to the energy transition
C. Conduct a simple experiment to illustrate the photovoltaic effect

2. To help students understand how a photovoltaic cell works, you have:

A. Created a simple electrical assembly
B. Used simulation software
C. Explained using video
D. Video

3. In order to assess students' knowledge of the different components of a photovoltaic installation, you have:

A. Organized an online quiz
B. Answered individual exercises
C. Created an installation diagram

4. To make learning more concrete, you have:

A. Visited a photovoltaic installation
B. Implemented a project to build a mini-solar grid
C. Simulated the sizing of a system for a household

5. To differentiate your teaching, you have:

A. Offered additional online resources
B. Organized level-based groups
C. Adapted exercise instructions

6. To encourage student participation, you have:

A. Organized discussions on solar energy issues
B. Created working groups to solve problems
C. Encouraged peer-to-peer exchanges

7. What administrative task(s) did you perform in connection with this module?

A. Prepared teaching materials
B. Corrected homework
C. Evaluated the skills acquired by the students

8. What difficulty did you encounter most frequently when carrying out these tasks?

A. Lack of suitable equipment
B. Time management
C. Student motivation

9. Which digital tool(s) have been most useful to you?

A. Online learning platforms
B. Simulation software
C. Presentation creation tools
D. Videos

10. If you had to redo this module, what task would you like to develop further?

A. Experimental Activities
B. Group Projects
C. Formative Assessment

11. Do you prefer to teach through online courses or through course materials?

A. Online Courses
B. Course Materials

12. Do you take into consideration the proposed QR codes?

A. Yes
B. No
C. Sometimes

13. Do you have internet at school?

A. No
B. Yes

14. Do you think all students have smartphones?

A. Yes
B. No

15. Do you have any suggestions for improving the teaching of this module?

A. Yes
B. No
C. Reduce calculation length
D. Lack of equipment and long calculations

Insights into the current situation of technological education at primary schools – illustrated by the example of Germany

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Abstract

The worldwide importance of technological education cannot be overstated (Jones, 2009). Technology literacy is essential for responsible participation in modern society (Mammes & Zolg, 2015) and has been integrated into educational systems across Europe (De Vries, 2018). At the same time, technological is ubiquitous in everyday life and shapes the environment in which children grow up (Möller & Wyssen, 2018). Despite the formal inclusion of technological education in curricula, it remains unclear to what extent it is implemented in primary schools and what factors contribute to its realisation. One of the seminal studies in German-speaking countries, conducted by Möller et al. (1996), found that fewer than half of the surveyed teachers incorporated technological into their instruction. Moreover, the study reported that only one in four teachers felt competent to deliver technological education. According to Mietzel (2017), teachers' self-efficacy beliefs are among the most influential factors affecting teaching practices. Consequently, teachers' self-efficacy beliefs in the domain of technological may play a key role in the implementation of technological education. Based on these research gaps, the present study seeks to address the following questions:
a) To what extent is technological education implemented in primary schools?
b) To what extent are (prospective) teachers' self-efficacy beliefs in the domain of technological associated with the implementation of technological education?
To address our research questions, we conducted an extended replication study. The two pilot studys involved N = 67 and N = 24 prospective teachers during their practicum semester. Preliminary findings from the pilot study suggest that technological content was integrated into "Sachunterricht" by only one in five (prospective) teachers surveyed. Based on these results, the outlook outlines the next steps in the ongoing research project.

Key Words: primary school, technological education, teachers behaviour, self-efficacy beliefs.

1. INTRODUCTION

Technology has become an integral part of contemporary life, shaping children's everyday experiences in diverse ways (Möller & Wyssen, 2018). Nevertheless, many children's understandings of technological remain limited to the operation and use of technological devices. The functional principles and developmental contexts of technological solutions often remain concealed, akin to a black box (Möller, 2002). This highlights the relevance of the topic and underscores the essential importance of technological education. Particularly in the context of primary education, technological education holds a special significance. Despite its relevance, technological education is not established as a separate subject in German primary schools (Schröer & Tenberge, 2023); instead, when it is taught, it is usually integrated into "Sachunterricht" or, in some federal states, into craft lessons.This paper explores how technological-related content is implemented within "Sachunterricht" and to what extent the self-efficacy beliefs of (prospective) teachers are associated with this implementation. To this end, the following section examines the factors that influence teacher behaviour in "Sachunterricht", with one of these factors, the self-efficacy discussed in greater detail. Based on this foundation, the research questions are derived, followed by a presentation of the methodological design of the pilot study and initial findings. The outlook concludes with a discussion of the proposed next steps.

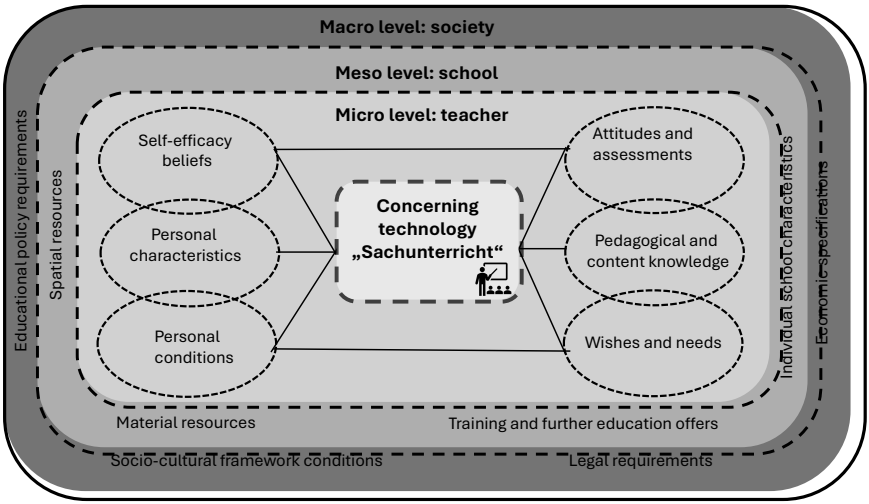
2. THEORETICAL FRAMEWORK

technological education isn`t established as an independent subject in German primary schools but rather is addressed and conveyed within the framework of "Sachunterricht" (Schröer & Tenberge, 2023). The fundamental concept of "Sachunterricht" is to stimulate children's learning about their environment from five different subject area – scientific, social, geographical, historical, and technological. This concept is referred to as multiperspectivity (Thomas, 2022). Multiperspectivity entails addressing topics not in a one-dimensional, subject-specific manner, but rather in a multidimensional way that considers various perspectives (Köhnlein et al., 2013). The aim of "Sachunterricht" is to support pupils in developing a subject-related understanding of their natural, technological social, and cultural environment. This understanding enables pupils to orient themselves within this environment, act responsibly, and participate reflectively and actively (Society for Didactics in "Sachunterricht" (GDSU), 2013).

To meet these educational goals, perspective "Sachunterricht" teachers must receive comprehensive training in all five perspectives during their university education. Despite several cross-regional frameworks for the structuring of "Sachunterricht" degree programmes (Conference of Ministers of Education (KMK), 2024; Lauterbach, 1996; Lauterbach et al., 1983), each institute of education independently designs and defines its own curriculum for the subject "Sachunterricht" and its didactics (Becher et al., 2019). These programmes differ not only in terms of scope but also in their content. However, it remains unclear to what extent prospective teachers are trained within the technological perspective. Möller et al. (1996) found that the less contact teachers had with technological content during their university education, the more insufficiently technological education was addressed in "Sachunterricht". However, it is not only

contact with technological during university studies that influences the implementation of technological-related content in "Sachunterricht". The following heuristic model – based on Möller et al. (1996) – identifies possible factors that may influence the individual behaviour of (prospective) teachers concerning technological-related "Sachunterricht". For the sake of research efficiency, the following chapter focuses exclusively on the influence of one highly relevant micro-level factor: self-efficacy beliefs (Bandura,1986).

Figure 1.
Heuristic model (based on Möller et al. (1996))



2.1. Influencing factor at the micro level: self-efficacy

One of the influential factors shaping behaviour concerning "Sachunterricht" is the self-efficacy of the individuals involved. The concept of self-efficacy originates from the theoretical work of Albert Bandura. Bandura (1986) emphasised that cognitive, motivational, emotional, and behavioural processes are primarily regulated by individuals' subjective beliefs (Schwarzer & Jerusalem, 2002). Self-efficacy refers to a person's subjective confidence in their ability to successfully cope with new or challenging demands based on their own competencies. These beliefs are highly individualised; it is not only essential to know which competencies are required, but also to believe in one's own skills to acquire and apply them. Thus, it is possible for an individual to possess the necessary knowledge yet still consider themselves incapable of mastering a task - this constitutes a low level of self-efficacy (Rustemeyer, 2011).

Self-efficacy significantly influences the level of effort invested in a task, the persistence with which an individual approaches the task, and how they handle failure. Rammsayer and Weber

(2016) argue that self-efficacy is a decisive factor in whether individuals approach challenges at all and how they engage with them. Generally, individuals with a high level of self-efficacy demonstrate greater perseverance and resilience. Mietzel (2017) identifies self-efficacy as one of the most influential characteristics for teachers and for professional conduct in teaching. The most important determinant of self-efficacy is experience gained through one's own actions. Positive experiences strengthen self-efficacy, whereas negative ones can weaken it. Rohnstock (2012) highlights that, in addition to personal experience, external factors - such as parental background - can also affect teachers' self-efficacy beliefs. Self-efficacy beliefs are also highly context- and content-specific, developing through experience within a particular domain. Therefore, teachers with generally high self-efficacy beliefs do not necessarily exhibit similarly high self-efficacy in technological domains (Mietzel, 2017). Schwarzer and Warner (2014) have shown that teachers with strong self-efficacy beliefs. They are more inclined to experiment with new teaching methods and are more open to innovative strategies. Despite these findings, the significance of self-efficacy beliefs in the context of technological education within "Sachunterricht" has so far received little attention in research. However, theoretical contributions (Schwarzer & Warner, 2014; Rustemeyer, 2011; Bandura, 1986; Mietzel, 2017) suggest that self-efficacy beliefs may play a crucial role in the implementation of technological content in classroom settings. Mammes (2008) argues that, in addition to curriculum guidelines, the implementation of technological education is strongly influenced by teachers' beliefs in their competencies.

3. PROBLEM OUTLINE

As the previous chapter demonstrated, the factors influencing teachers' behaviour with regard to technological-related "Sachunterricht" can be diverse and have a significant impact on the implementation of technological content in teaching practice. Currently, there are very few empirical studies on this topic in German-speaking countries. The TeBiS study (technological education in "Sachunterricht") by Möller et al. (1996) examined the implementation of technological content in "Sachunterricht". As well as the influence of various variables, such as teachers' personal interest in technological, their engagement with technological during teacher training, their self-assessed competence, and their attitude towards the relevance of technological content in "Sachunterricht". The authors show that fewer than half of the surveyed teachers integrated technological content into their lessons. Furthermore, only around a quarter of the teachers felt sufficiently competent to teach technological-related general studies independently. It can be assumed that this inadequate situation has not fundamentally changed.

This assumption is supported by the results of the 2023 TIMSS (Trends in International Mathematics and Science Study), which reveal a continuous downward trend in science achievement among German fourth-grade students since 2007. Only 9% of the students tested reached the highest proficiency level, while approximately 30% were assigned to the two lowest levels (Schwippert et al., 2024). Although TIMSS assesses only scientific competencies, conclusions can be drawn regarding the technological understanding and competence of primary school children. technological is largely based on scientific principles and transforms them into application-oriented, problem-solving approaches for practical challenges. While science is primarily concerned with understanding and explaining natural phenomena, technological

employs this theoretical knowledge to develop and construct targeted and solution-oriented applications (Schmidt, 2002).

Further insights into the role of technological education within "Sachunterricht" are provided by the schoolbook analysis conducted by Blaseio (2004). Her study revealed a continuous decline in the presence of technological content over the decades; by the late 1990s, technological topics accounted for only about 5 per cent of "Sachunterricht" content. Beutin et al. (2023) also found, through their analysis of the "Sachunterricht" framework plans, that subject content in the STEM field is unevenly distributed, with the technological perspective accounting for only 9.8 per cent throughout Germany. Giest (2012) concludes that technological education in primary schools remains in a state of crisis, despite the increasing technologisation of societal life. Given the fragmented and outdated state of research (Möller et al., 1996; Blaseio, 2004), it remains unclear to what extent technological content is currently implemented in "Sachunterricht", and the extent to which the factor described in Chapter 2, the expectations of self-efficacy beliefs, influences the implementation of technological content.

4. INTERIM CONCLUSION AND RESEARCH QUESTIONS

As highlighted in the previous section, the TeBiS study by Möller et al. (1996) represents the most comprehensive empirical investigation to date concerning the implementation of technological education in German primary schools. However, this study is now nearly three decades old, and no large-scale empirical follow-up has been conducted since then. This indicates a substantial research gap regarding the status and influencing factors of technological education in the context of "Sachunterricht".

Chapter 2.1 has shown that teachers' self-efficacy beliefs significantly influence their instructional behaviour and openness to pedagogical innovation. Considering this, it can be assumed that teachers who exhibit high self-efficacy beliefs in the field of technological may be more inclined to adopt new teaching strategies and to actively incorporate technological content into their lessons. Nevertheless, empirical evidence on the relationship between self-efficacy beliefs in the technological domain and the actual implementation of technological education at the primary level remains limited. This research project aims to address this gap by revisiting and extending the findings of Möller et al. (1996) in the context of current educational demands and teacher training practices. Accordingly, the following research questions guide the study:

1. To what extent is technological education currently implemented in German primary schools?
2. To what extent are (prospective) teachers' self-efficacy beliefs in the technological domain associated with the implementation of technological education?

5. METHODOLOGY

To answer our research questions, we designed and piloted an extended replication study based on the study by Möller et al. (1996) and piloted. The aim of this extended replication study was to use an extended questionnaire to assess the self-assessments of (prospective) teachers regarding their self-efficacy beliefs (based on Doll & Meyer, 2021), their previous experiences, and their pedagogical and content knowledge in relation to technological-related content in general studies. The original questionnaire by Möller et al. (1996) was expanded for this purpose to include items on the (digital) equipment of the school for technological-related "Sachunterricht" and self-efficacy expectations regarding teaching with (digital) tools. All participants were informed in advance via an information sheet that no personally identifiable data would be collected and that participation was voluntary. They were also informed that the data would be treated confidentially and not shared with third parties.

5.1. Method

The first pilot phase was conducted in spring 2025 at Paderborn University (Germany) with 67 pre-service teachers during their practical semester. The practical semester in Germany forms part of the university's programme and aims to combine theory and practice. One of the students' core tasks is to deliver and teach lessons under supervision. The sample consisted of 48 prospective primary school teachers and 19 students training to become special education teachers (59 female, 8 male). All participants were enrolled in the subject "Sachunterricht" and had already gained initial teaching experience prior to the data collection. The primary goal of this first phase was to critically evaluate the self-efficacy beliefs scale and to revise the questionnaire based on the collected data. The second data collection phase was subsequently conducted at the University of Münster (Germany), involving 24 pre-service primary school teachers (23 female, 1 male) also in their practical semester. Both data collections used a paper-and-pencil questionnaire format based on participants' self-assessments.

The questionnaire covered several key areas: First, it was determined whether the participants were teaching science at the time of the survey. Then, personal interest in technological topics was measured using eight questions answered on a four-point Likert scale. Another focus was on previous experience with technological content during training, examining whether and to what extent technological content had already been covered. Teachers were then asked to indicate whether they had already addressed technological content in general studies during their practical semester. Teachers without such experience were asked to indicate possible reasons for the absence of technological -related topics in their teaching.

Another central component of the questionnaire was the scale for measuring self-efficacy beliefs regarding the implementation and teaching of technological -related content in general studies. This scale consists of twelve items that were rated on a six-point Likert scale. In addition, participants were asked to assess their pedagogical and subject-specific competencies in the key areas of general studies. The structure of this scale was based on the content areas defined by the Society for Didactics in "Sachunterricht" (GDSU, 2013) for the technological perspective and included, among other things, the following area: 'Conversion and use of energy'.

5.2 Preliminary Findings

The results of the initial pilot study involving student teachers (N = 67) during their practical semester at Paderborn University indicate that 80.6 per cent (n = 54) of the respondents didn`t address technological content in "Sachunterricht" during their practical teaching in schools. Of the n = 54 teacher students who didn`t integrate technological content into Sachunterricht, 48 were female and 6 were male teacher students. The reasons cited included a lack of time, the requirement to cover other (prescribed) topics, or the perception that technological subjects are not particularly relevant within the context of "Sachunterricht". One student teacher reported feeling insufficiently confident to address technological topics in "Sachunterricht", stating: "I have hardly any knowledge about it, and I'm not really interested in it" (BSSOSE_25_12). Only a minority of student teachers – fewer than one in five (n = 13) – had the opportunity to gain experience in teaching technological content within "Sachunterricht" during their school placement. The following table presents the frequency with which technological content was addressed during the practical semester.

Table 1. Duration of implementation of technological content in "Sachunterricht" in Paderborn

Sample (N=67)	Duration of Implementation	Percentage
n=54 (♂= 6; ♀= 48)	No implementation	80.6
n= 4 (♂= 2; ♀= 2)	In 1–2 lessons	6.0
n= 7 (♀= 7)	In 3–5 lessons	10.4
n= 2 (♀= 2)	More frequently	3.0

The analysis of the results from the University of Münster (N = 24) reveals a similar pattern: only approximately one in five student teachers (20.8 per cent) reported addressing technological content in "Sachunterricht" during their practical semester. Of the 24 student teachers surveyed, 19 indicated that they had not taught any technological topics in "Sachunterricht". The reasons given mirrored those identified at Paderborn University, including limited time and a curricular focus on other (often prescribed) topics. Additionally, two students cited a lack of material resources at the schools as a further reason for not covering technological content. The findings from the pilot studies conducted in Paderborn and Münster demonstrate that only around one in five student teachers addressed technological content during their practical semester, with similar reasons reported at both locations.

To answer the second research question, the self-efficacy beliefs of teacher, students were assessed using twelve items (based on Doll & Meyer, 2021). Participants were asked to rate their confidence on a six-point Likert scale (1 = not at all confident to 6 = fully confident) regarding the following domains: teaching technological topics, diagnosing in technological -relates issues

in “Sachunterricht”, learning-related knowledge in technological “Sachunterricht”, and technological content knowledge.

Table 2. Technological-related self-efficacy beliefs of students in their practical semester

Scale	Results Paderborn (N=67)	Results Münster (N=24)
Overall (self-efficacy beliefs) (12 Items)	M= 3.69 (SD= 0.59)	M= 4.07 (SD= 0.59)
Teaching technological topics (3 Items)	M= 3.90 (SD= 0.77)	M= 3.93 (SD= 0.75)
Diagnosing in technological “Sachunterricht” (3 Items)	M= 4.07 (SD= 0.77)	M= 4.04 (SD= 0.79)
Learning-related knowledge for technological “Sachunterricht” (3 Items)	M= 3.37 (SD= 0.80)	M= 4.30 (SD= 0.67)
technological content knowledge (3 Items)	M= 3.44 (SD= 0.68)	M= 4.04 (SD= 0.79)

Table 2 shows that the mean scores for technological-related self-efficacy beliefs among the student teacher samples from Paderborn (M = 3.69) and Münster (M = 4.07) fall within the range of partially confident (1.0–1.4 = not at all confident; 1.5–2.4 = very little confidence; 2.5–3.4 = low confidence; 3.5–4.4 = partial confidence; 4.5–5.4 = fairly confident; 5.5–6.0 = fully confident). Accordingly, student teachers from both Paderborn and Münster consider themselves partially confident in their ability to integrate technological topics. In the next step, point-biserial correlation was calculated. The results from University of Paderborn revealed a weak correlation (r = .095, p =.446) between the implementation of technological content in “Sachunterricht” and self-efficacy beliefs regarding the teaching of such content. A similar weak correlation (r = 0.156, p = 0.468) with insignificant results was found at the Münster site. These insignificant correlations may be explained by the fact that student teachers have limited influence over the selection of topics and content during their practical semester. Even if they have high self-efficacy expectations in the technological field, they often do not have the opportunity to implement technological content in “Sachunterricht”.

6. OUTLOOK

The starting point for this pilot study was to examine the extent to which technological content is integrated into “Sachunterricht” and to what extent the self-efficacy beliefs of student teachers during their practical training semester correspond with the implementation of technological-related aspects of “Sachunterricht”. The quantitative analysis of the data, which remains limited at this stage due to the small sample size, provides initial indications regarding the current state of technological education within “Sachunterricht” and its relation to the self-efficacy beliefs of the student teachers involved. The findings suggest that – in comparison to the study by Möller et al. (1996) – no substantial progress can be observed in the implementation of technological content in “Sachunterricht”. Furthermore, no statistically significant correlation was identified between the student teachers’ self-efficacy beliefs in the technological domain and the actual implementation of technological content. Analysis of the results showed that 18.6% of female

and 25% of male student teachers surveyed addressed technological content in “Sachunterricht”. This gender-specific difference in the implementation of technological content in “Sachunterricht” should be considered in the project's future stages. Nevertheless, it is important to emphasise that the results derived from the two research sites offer only preliminary insights and, due to the limited sample size, cannot be generalised to other cohorts of student teachers. To derive representative statements regarding the integration of technological content in “Sachunterricht”, subsequent research phases will involve expanding the sample size and including not only student teachers in their practical semester, but also in-service teachers. In the long term, the study aims to be extended internationally to compare and evaluate the state of technological education within “Sachunterricht” at the primary school level across different countries.

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Using two different methodologies to demonstrate the necessity of transparency in data analysis within technology education qualitative research.

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Abstract

Qualitative research, underpinned by interpretivism, is utilised to gain in-depth insights into an area under investigation due to its ability to capture the richness of data gathered rather than attempting to broadly generalise findings in quantitative research underpinned by post-positivism. At the centre of qualitative research is the researcher themselves, often described as an 'instrument' during data collection and analysis. Their capacity to interpret the data through reflexivity, and their selection, use and understanding of a methodology, directly impacts the validity, reliability and outcome of the research. The openness of interpretation therefore requires explicit disclosure of the source of the findings, through elaborating on the methods, procedures and processes undertaken and the researcher's decisions to support the validity and reliability of the found results, and its methodological consistency. However, transparency in data analysis procedures has become an identified concern within qualitative research in technology education, particularly within the areas of the saturation point of data collection, disclosure of unexpected opportunities and challenges, and the positionality of the researchers.

This paper aims to demonstrate the need to be transparent in the procedures of qualitative data analysis. To exemplify the importance of transparency, a comparative study was conducted in which the same dataset, collected from interviews with 5 in-service technology teachers in Ireland, was analysed under two different methodologies, phenomenology and classical grounded theory. The observations from each highlight the differences in the nature of findings which can be derived from the same dataset depending on analytic lens. This paper forms a discussion on the differences between phenomenology and classical grounded theory in data analysis, the ease with which researchers may unintentionally shift between methodologies, and the impact that non-transparency could have on the validity, reliability and methodological consistency of qualitative research in technology education.

Key Words: Qualitative Research, Data Analysis, Classical Grounded Theory, Phenomenology, Technology Education.

1. INTRODUCTION

Qualitative research is utilised to understand and make sense of phenomena from the perspectives of participants (Merriam, 2002) and it allows the research design to be flexible during the research process as decision-making moments arise (Reiter et al., 2011). Qualitative research is inherently biased because the researcher takes the position as the "instrument" for data collection and analysis, therefore the assurance of rigor and trustworthiness relies on their judgements of coding, categorising, decontextualising and recontextualising the data (Starks & Brown Trinidad, 2007).

A study from Buckley et al (2022) suggests that qualitative research in technology education can often lack transparency in the dissemination of the researcher's positionality within investigations, whether saturation was reached in data collection, and in how power relations were managed between themselves and the participant. Their study utilised a modified behaviourally-anchored rating scales instrument developed by Aguinis and Solarina (2019) to score each analysed research article and found that no qualitative research article in the dataset scored a perfect score for transparency, with considerable variance across manuscripts (Buckley et al., 2022). This concern for the transparency in the reporting of qualitative research in technology education raises the need to demonstrate the value of transparency.

Previous research conducted by McDyer et.al (2022, 2023) identified a need to gain insight into the manifestation of design in classroom practice in technology education, based on a lack of an awareness of practices identified through a scoping review (McDyer, 2022) and a narrative literature review (McDyer, 2023). Following these results, an interview study was conducted where practicing technology education teachers were interviewed to explore design in classroom practice (McDyer et al., 2024).

This paper utilises the transcripts from this interview study to demonstrate the differences between phenomenology and grounded theory methodologies and to highlight the importance of transparency in analysis and the possibility of departure from one methodology after data collection to analyse the data through a different method as similarly conducted by Starks and Brown Trinidad (2007) . The goals of this paper are to;

- provide clear insight of the impact that the different methods of data analysis can have on the results generated from the same data, analysed separately and

- to demonstrate the need for transparency during the analytic process to show that the analysis is aligned with the methodology used for data collection.

2. LITERATURE REVIEW

2.1. Phenomenology

Phenomenology first emerged as a philosophy by Edmund Husserl and further developed by Martin Heidegger which focused on consciousness and essence of phenomena towards an approach to research focusing on existing and hermeneutic (interpretive) phenomena (Kafle,

2011). Phenomenology is about a deep analysis and description of the experience of others (Reiter et al., 2011), and uses lived experiences to describe how meaning is created (Starks & Brown Trinidad, 2007) through the perception of human's, and not from a theoretical standpoint (Bevan, 2014). Interviewing is seen as the one legitimate source for information and the sampling technique utilised is purposive and prescribed from the start (Goulding, 2005).

2.1.1 Designing a phenomenological study:

The participants to be interviewed are selected through purposive sampling before the study commences (Goulding, 2005). Typically, there are between 1 and 10 participants included in a study similar to this (Starks & Brown Trinidad, 2007). As this methodology is interested in uncovering common features of lived experiences, from a population experiencing the phenomenon, an increased diversity to the population will broaden the range from which the phenomenon is experienced. However, it is suggested that gathering data from a small population could suffice in uncovering key insights, dependent on their ability to provide a detailed account of their experience with the phenomenon (Starks & Brown Trinidad, 2007). Phenomenologists must support participants to 'revisit' their lived experiences and this can be achieved in numerous ways through interviewing the same participant numerous times (Lauterbach, 2018). Seidman's (2006) method to interviewing requires the use of three interviews per participant, the first, to gain personal context and history of participant, the second, to explore the participants reconstruction of the experience and the third, to allow the participant to reflect on the meaning of their experience (Bevan, 2014; Lauterbach, 2018). An alternative method is that of van Manen (2016), where he encourages a more conversational interview that has two purposes, 1) to explore and develop a rich understanding of the phenomenon and 2) engage in a conversation around the meaning of experience (Lauterbach, 2018).

The researcher takes the role of an active listener, taking the words from the participant at their intended meaning and asking probing questions through a semi-structured or even unstructured protocol. The openness nature of these interviews leads itself to stray away from the intended aim of the research study, therefore it is important that the researcher is clear about the phenomenological question asked in the study (van Manen, 2017a). The researcher must ensure that they do not impose any preconceived biases or opinions during the interview, referred to as 'bracketing' (Reiter et al., 2011).

2.2. Grounded Theory

Grounded theory was founded by Glaser and Strauss from sociological research with the goal of enabling researchers to systematically generate a substantive theory that was grounded in empirical data (Walker & Myrick, 2006) from the investigation of basic social processes in environments in which it takes place (Starks & Brown Trinidad, 2007). It is recognised that grounded theory combines the richness and depth of qualitative research with the logic, rigor and systematic analysis inherent with quantitative survey research (Walker & Myrick, 2006). Since grounded theory's emergence in the 1960's there has been much contention surrounding the perceived effective procedures involved in the data collection and analysis, so much so that there are several different forms of grounded theory, including; Classical, Straussian and Constructivist grounded theory (Kenny & Fourie, 2015). Figure 1 illustrates the differences between these forms

of grounded theory. When grounded theory is utilised with objectivity and a critical realist philosophy, the methodology fits a postpositivist in inquiry paradigm (Annells, 1996). Whereas when it is relativist, subjectivist and dialectical when utilised, then this methodology fits a constructivist paradigm of inquiry (Annells, 1996). Therefore, the researcher that utilises grounded theory, will personally 'suit' one of the forms of grounded theory that best fits their beliefs, and follow the unique procedures of that form. To limit the scope of this paper, there is not a rigorous comparison between the different forms, but rather an insight into the chosen method of classical grounded theory and how it impacts study design and data analysis procedures.

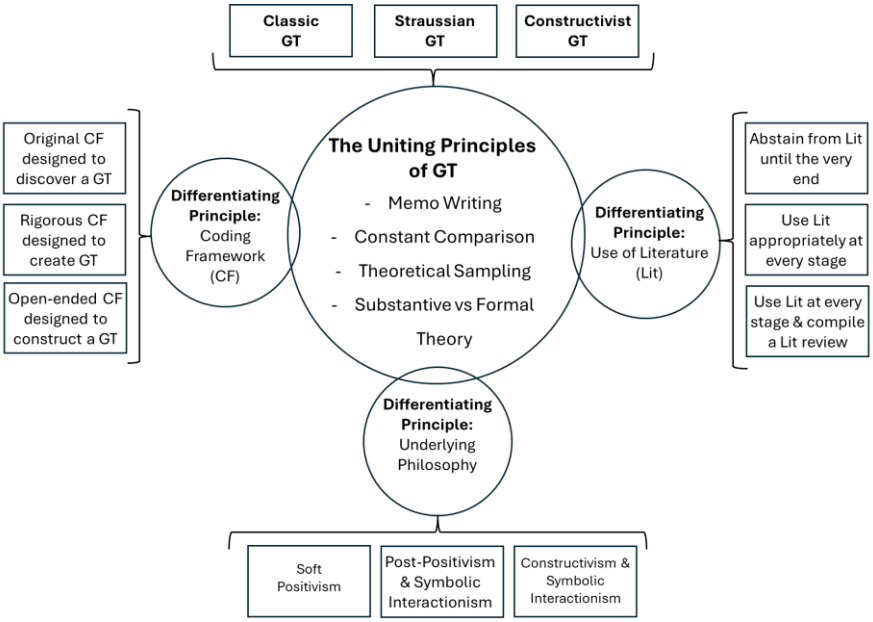

Figure 1. The uniting and differentiating principles of grounded theory (Adapted from Kenny & Fourie, 2015).

The role of the researcher is to be the 'instrument' for data collection, often through interviewing a population. As is widely known in qualitative research, the researcher takes up a position that is close to the data whereby their interaction, bias and preconceptions can impact the gathered data. It is foundational that the researcher must allow the data speak for itself (Walker & Myrick, 2006), which is further expanded by Glaser and Strauss (1967) when it is described that a theory must be discovered within the data, by the researcher, and then refined through the involvement of literature. As with phenomenology, the researcher plays an active listening role, taking the meaning of participants words at intended value and asking probing questions as the interview develops (Starks & Brown Trinidad, 2007).

2.2.1. Designing a grounded theory study:

At the heart of grounded theory is the inability to predetermine the sample population to investigate for the entire project. It is imperative that the researcher only plans for the preliminary stages of a study, the initial gathering of the data and allows for the progressive and fluid nature of grounded theory to reveal the follow-up population samples (Kenny & Fourie, 2015). Upon the analysis of initial data, the researcher will only then recognise the need for further data through the identified gaps and employ *theoretical sampling* to collect further data from theoretically relevant populations (Glaser & Strauss, 1967). What this open study design allows for is the discovery of unexpected concepts that could change the direction of the study, although still within the remit of the research questions, to discover unique and novel results (Kenny & Fourie, 2015).

Interviews are semi-structured whereby the researcher must ensure to limit their preconceptions and biases during the interview where they are mostly receptive during the initial gathering of data (O' Connor et al., 2019). As the project progresses and concepts and gaps are revealed, only then will the researcher commence to ask more refined and focused questions, supported through theoretical sampling (O' Connor et al., 2019). Classical grounded theory describes interviews to be non-structured and not long in duration to prevent leading the interview in a certain direction or to impose bias (O' Connor et al., 2019).

2.3. Phenomenology v Grounded Theory

There are similarities between phenomenology and grounded theory, where they both value the rich data that is gathered during interviews that are semi or unstructured, the use of 'bracketing' to ensure that the researcher's preconceptions and biases do not impose unwarranted direction on the interviewee and the value of investigating peoples lived experiences of phenomenon under investigation. This raises concerns as to the need for transparency in the reporting of data collection procedures within phenomenological and grounded theory research studies to ensure trustworthiness.

Although often perceived to be similar in nature, the methodologies differentiate from one another. The phenomenological process is interested in seeking to understand lived experiences often contrasted with abstract interpretations of experience, whereas the grounded theorist is concerned with investigating how social structures and processes impact how things are accomplished through a given set of social interactions (Starks & Brown Trinidad, 2007). Phenomenologists interview a population who have experienced the phenomenon of interest, whereas grounded theorists interview a population who have experienced the phenomenon of interest, under different conditions (Figure 2) (Starks & Brown Trinidad, 2007). There lies a difference in the design of each study, mainly being that phenomenologists will select their participants prior to the commencement of data collection, and the grounded theorist will select initial participants and will allow for the results of this to dictate where the next population of participants will come from. This is where the interview process significantly differs, as questions will significantly develop in a grounded theory study between interviews compared to phenomenology. Finally, the intention of a phenomenological study is to capture the essences of lived experiences of a phenomenon, so that new meaning can emerge that will enhance our understanding through a story-like description of themes (Lauterbach, 2018). The intention of

grounded theory is to systematically generate a substantive theory that supports the understanding of basic social processes.

	Phenomenology	**Grounded Theory**
History	European Philosophy	Sociology
Philosophy	There exists an essential, perceived reality with common features	Theory is discovered by examining concepts grounded in the data
Goal	Describe the meaning of the lived experience of a phenomenon	Develop an explanatory theory of basic social processes
Methodology Formulating a research questions	"What is the lived experience of (the phenomenon of interest)?"	"How does the basic social process of (X) happen in the context of (Y environment)?"
Sampling	Those who have experienced the phenomenon of interest	Those who have experienced the phenomenon under different conditions
Data Collection: Observations	Observe participants in the context where the phenomenon is experienced	Observe participants where the basic social process takes place
Interviewing strategy	Participant describes experience; interviewer probes for detail, clarity	Participant describes experience; interviewer probes for detail, clarity
Analytic Methods Decontextualization & Recontextualization: Process of coding, sorting, identifying themes and relationships, and drawing conclusions	Identify descriptions of the phenomenon; cluster into the discrete categories; taken together, these describe the "essence" or core commonality and structure of the experience	Open, axial, & selective coding: Examine concepts across their properties & dimensions; develop an explanatory framework that integrates the concepts into a core category
Role of Analyst's Views	Bracket views	Bracket views
Audience	Clinicians, practitioners & others who need to understand the lived experience of the phenomenon of interest	Researchers & practitioners who seek explanatory models upon which to design interventions
Product	A thematic descriptions of the pre-given "essences" and structures of lived experiences	Generate theory from the range of the participants' experience

Figure 2. The similarities and differences of two interpretive approaches to qualitative research (Adapted from Starks & Brown Trinidad, 2007).

The similarities between data collection procedures could misleadingly allow for possible departure from one methodology into the other, particularly during data analysis procedures. From investigating the differences between methodologies shows how this would impact not only the trustworthiness of the study but also the intended results and investigation from the

methodology used to design the study. The procedure of their respective data analyses is found in the methodology section, whereby the same interview data transcripts are analysed using both sets of procedures to identify the differences in results found and the necessity to maintain aligned with the chosen methodology used to design the study.

3. METHODS

To explore the differences between phenomenology and grounded theory, with particular attention paid to how they can generate different results and findings, a set of interview transcripts were analysed under both methodologies independently. The transcripts that were used were from McDyer's (2024) study that had the following research question 'how does design manifest in classroom practice'. This research question was used to guide the analysis of the transcripts.

3.1. Data Collection

Online semi-structured interviews were employed utilising an interview protocol that conformed with the principles of classical grounded theory as discussed in section 2.2.1. The interviews ranged from 45 minutes to 1 hour and 15 minutes and each participant was interviewed once. Microsoft Teams and Zoom were used to conduct the interviews which were recorded and then transcribed, anonymised and stored in a secure online cloud folder of the principal investigator. Sample questions included *what role does design have in your subjects, how would you describe your confidence in developing design capable students,* and *can you tell me what a design task looks like in your class?*

3.2. Participants

Purposeful sampling was employed to anticipate the richness and relevance of information that will yield insights and in-depth understanding of the research questions (Gentles et al., 2015). The inclusion criteria for participants were as follows:

- an in-service technology education teacher at secondary level education in Ireland,
- fully qualified in the discipline of technology education,
- teaching at least 1 subject within the 4 disciplines of technology education,
- the sample had to include a mix of male and female participants that range from early career teachers to experienced teachers.

There were 3 male and 2 female participants in this study, with an age range between 26 - 52 years old. As the data collection procedure of the grounded theory study was only at the initial data collection phase where interviews were open, semi-structured and unfocused with theory generation, it was possible to adopt these transcripts to be analysed using phenomenology as well as classical grounded theory procedures.

3.3. Phenomenological Data Analysis

The immersion of the researcher into the data is necessary for phenomenological analysis and to ensure trustworthiness, they must ensure that they utilise 'bracketing' to recognise and set aside

their own prior knowledge, assumptions and biases to analyse participants insights with an open mind (Starks & Brown Trinidad, 2007). Van Malen (2017a) wrote about the misconception that phenomenological analysis uses methods of coding, categorising, searching for patterns, etc. as processes to support the uncovering of the essences of 'lived experiences' and 'phenomenal understanding and insights'. Van Malen (2017b) discusses that in order to allow for the pure nature of phenomenology to be achieved, a researcher must allow the phenomenon (lived experience) show itself in the way that it gives itself while living through it. Procedural methods to analysis is not necessarily the most effective method to uncovering 'phenomenal understanding and insight' but rather efforts of reflective writing, deep questioning, attentive reminiscing and sensitive interpretations of the meanings of human experience (van Manen, 2017b). Starks & Brown Trinidad (2007) discusses that phenomenological analysis is the capturing and writing of a story of the lived experiences and as a reader, come to envisage the phenomenon presented and come to the similar conclusion about what it means.

To analyse this data, memo writing, voice note taking and reflective writing was used to gather meaning from the lived experiences of the participants of the phenomenon. Initial familiarity and a deep dive into the data took place through transcribing the interviews, which then progressed towards a line-by-line analysis. This supported the researcher to find meaning in the data and the consistent reflection, questioning, memo writing and this reciprocal and iterative back and forth effort, allowed for insights to be gathered and meaning to be explored. Key words were highlighted, and labels were given to lines, paragraphs and/or sections that identified insights. From this, predominant themes were identified to disclose the insights of the participants lived experience and the results are reported in the next section are the thematic descriptions that provide meaning of the lived experience (Starks & Brown Trinidad, 2007; van Manen, 2017b, 2017a).

3.4. Grounded Theory Data Analysis

The classical grounded theory data analysis procedure is seen in Figure 3 (Holton, 2010). Inductive open coding was used to gather codes, and the transcripts were analysed line-by-line using NVIVO to support organisation of data and codes. Between each interview reflexivity took place in the form of voice notes and memo writing to capture initial thoughts on the data collected, discovering of gaps and to inform the subsequent interviews to follow.

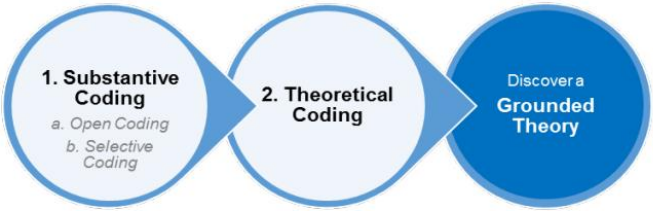

Figure 3. The coding procedure of classic grounded theory (Holton, 2010)

Memos were also used during coding to gather initial thoughts of the data, comparing incidents and codes, to direct future interviews in the direction that would present more rich and focused data and to understand emerging concepts. Essential to analysing this data was to be conscious of 'analytical paralysis' where when straying too far from the research questions that the data

becomes overwhelming and the generation of a theory will become unrealistic based on the scope of the data (Birks & Mills, 2015).

Constant comparison between codes and incidents informed the categorisation and conceptual grouping of codes. Once the data was analysed and a point of saturation was achieved, where no new codes were generated, the codes were grouped into categories and were conceptualised. To support conceptualising, each category was given a definition to prevent proliferation of the same or similar concepts with different names (Morse, 2004). Particular attention was paid to the wording of concepts to ensure that they are abstract of time, place and people' (Klag & Langley, 2013). During this process constant comparison between categories and codes was utilised, and the relationship between categories support the emerging of conceptual links.

4. FINDINGS

4.1. Phenomenological Analysis Findings:

Below are the results, from analysing the transcripts using the phenomenological analysis method. Outlined below are themes that describe the lived experiences of practicing technology education teachers' experience with design in classroom practice under the central research question previously stated.

4.1.1. Supporting design in classroom practice:

Participants described how they supported students through the design process when students were designing in the classroom. They described how they were confident in supporting design, providing feedback, being the catalyst for design inspiration and teaching the procedural knowledge and skills that would open more doors to students designing. It was also discussed that confidence grew through experience of supporting students designing.

4.1.2. Structured experience

Participants designed and implemented stage appropriate design tasks that progresses in complexity to ensure students were developing their design capabilities. It was discussed how consistent experience is vital to allow students to develop their design capabilities.

4.1.3. Culture

A culture where students are allowed to make mistakes, try new things, seek feedback from peers and teachers, and a positive fun environment support students designing.

4.1.4. Open ended and closed ended design tasks

Participants would implement both closed and open-ended design tasks for different ability classes. Closed ended design tasks, often associated with lower secondary education, are those in which students have minimal decisions to be made on the design *"with first years, they're all getting the same size piece. They have their choice of colour"* (Donna). Open ended design tasks would include more complex decisions e.g. what mechanism would you use and what material would exhibit the most appropriate properties for this element.

4.1.5. Design is secondary or added at the end of the project

Participants often described how design can be an additional element at the end of a procedural and closed ended project whereby they provide the student with designing a new element for the project. This is seen as a higher order activity, where the students who have finished the project, can then commence the design task**.**

4.1.6. Examples and samples

One technique that participants used was to showcase examples and samples of past projects and even similar artefacts to guide students' inspiration and ideation when designing.

4.1.7. Supporting the refinement of designs

Participants described that a key role in their support of students designing is their adopted role of the 'refiner' of the students' design iterations, concepts, ideas and artefacts. Teachers provide critical and formative feedback to students during various stages of their design processes. It is at this stage where teachers can identify issues of fixation, unrealistic manufacture or that the design does not meet the needs of the brief. This then supports the student to further refine their design towards a finalised solution.

4.1.8. Communicating

Communicating design iterations, concepts and ideas is a key part of the design process found in classroom practice. Participants often require students to complete sketches of CAD files of their design ideas, concepts, iterations and finalised artefact. It is described as a challenge for teachers, to support students to accurately represent their thoughts in a physical medium of communication.

4.1.9. Guided Instruction

The teacher goes from the instructor and information point at lower secondary education to the facilitator at upper secondary education. At lower secondary level the teacher asks questions that prompts students to think, like a catalyst for design inspiration, they plan strategic research activities and offer portfolio templates to guide designing. This progresses in upper secondary education where teachers reduce their guided instruction and expect students to take on more responsibility with managing their design process. Students are expected to carry out more independent research and that teachers plan around what students present them.

4.2. Grounded Theory Analysis Findings:

Below are the initial concepts that have been uncovered from the data, at this current stage of this project.

4.2.1. Design(ing)

Definition: A foundational level description of design as an entity and the inherent act of designing

Discussion: This concept was generated from a grouped category of codes where participants described their foundational understanding of the entity of design, the inherent act of designing, the value of design, the freedom through design, what makes design complex, the design process

and the interdisciplinary nature of design. The conceptual link between other concepts is displayed in Figure 4. Having a well-developed foundation for this concept will impact on the designer, the methods to fostering designers and the lack of knowledge in this concept can create or enlarge barriers.

4.2.2. Designer

Definition: What makes a person a designer

Discussion: This concept was generated from a grouped category of codes where participants described things that make students designerly, including decision making skills, self-evaluation ability, the description of who suits design and who doesn't suit design, the issue of design insecurity, the difference between learners from the beginning and skills to enable effective design. As seen in Figure 4, this concept has a relationship with the below concept of design pedagogy, because understanding what is the make-up of a designer will impact on the creation and implementation of design pedagogies. As discussed above, this concept links to the overarching concept of design(ing) and to the concept of barriers, as having underdeveloped skills and abilities can limit the effectiveness of being able to design.

4.2.3. Design Pedagogy

Definition: Teaching methods to foster designers

Discussion: This concept was generated from a grouped category of codes that indicated methods or insights to teaching design, assessing design and through identification of what is not teaching to design. Teaching design does not explicitly relate to teaching about design or the how-to of design but also consciously designing and facilitating activities to foster designers through designing. Figure 4 displays this concept's relationship to other concepts, paying particular attention to its relationship with the concept of barriers, as constraints such as resources and time can impact on the classroom practice of facilitating the teaching of design.

4.2.4. Barriers

Definition: What is constricting design in classroom practice

Discussion: This concept was generated from a grouped category of codes where participants identified limits and barriers to designing in classroom practice. This concept is founded upon participants discussion of the ambiguity of designing, the constraints such as time and resources, the difficulty from the teacher's perspective, the limited awareness of explicitly teaching how-to design, the uncertainty of teaching key designerly skills and the concern of unrealistic designing.

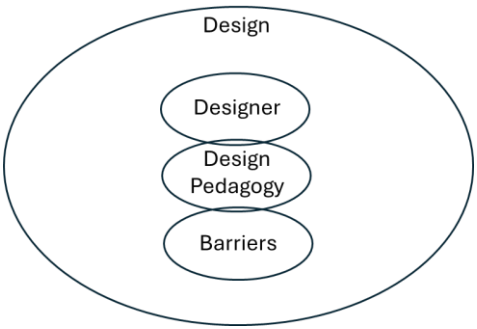

Figure 4. An iteration of the relationships between concepts generated from grounded theory analysis.

As this is an iteration of the relationship between concepts, there lies a need for further critical thought as to their graphical representation. Two outstanding questions here is why is design pedagogy below designer? And is the linearity of the graphic a true representation of the concept's relationships with one another. These are to be explored and answered in a follow-up paper.

5. CONCLUSION

The phenomenological findings showcase themes that are insights to how design manifests in classroom practice from the experience of teacher's lived experiences. Findings demonstrate the various methods and techniques that they use as well as the overarching role of the teacher as the supporter in the students' design process. These observations are beneficial to understand the multi-faceted nature of design in classroom practice in this specific context. There were limited explicit examples provided of teaching the how-to of designing, which could (if this remained an observation with further data collection and phenomenological analysis) raise the question, can we teach the how-to of designing?

The classical grounded theory findings showcase fundamentally different insights, concepts at a higher level of abstraction than that of the themes identified through phenomenology. This level of abstraction allows the findings to be more transferable to other contexts, as the higher level of abstraction, the further away it is from the data found in niche contexts (Morse, 2004). However, as with the phenomenological findings, which stem from the same data, this grounded theory findings emerged from one round of interviews and further collection will continue in this tradition until saturation is reached. There lies a philosophical remit to these results, whereby they present foundational level discussion on what design as an entity is and its inherent act and what it means to be a designer, labelled as high-level concepts. The lower-level concepts of design pedagogy and barriers are of less abstraction and are somewhat more practical in nature, which leaves questions about the higher concepts unanswered. Therefore, the observations from this phase of the study will be utilised in theoretical sampling to determine a population for a next round of more focused interviews.

This study shows the possibility of transitioning to a different methodology during qualitative data analysis procedures and the difference in potential observation types, indicating a possible

validity threat if analysis is misaligned with the study's design methodology. The intention of this paper is not to present accounts of completed phenomenological or grounded theory studies. Instead it is to illustrate the need for internal consistency in research designs from data collection through to analysis and presentation. The actual observations in the paper are legitimate, though limited in that participants were only interviewed once as part of a first data collection phase within an ongoing classical grounded theory study.

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Responsible technological innovation in teaching practices: a first approach.

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Abstract

Technological education plays a central role in the acculturation of young people with the societal challenges posed by the introduction of new technologies. In France, education in technological innovation is already well established in school curricula and aims to develop students understanding of the underlying dynamics, benefiting both users and future technicians. However, in response to contemporary global challenges—whether environmental, social, or ethical—there is a growing demand to reorient this education towards a more responsibility-centered approach. In this context, education in responsible technological innovation emerges as a relevant pathway for rethinking curricula and training citizens capable of designing and using technology in an ethical and sustainable manner.

Our research aligns with this perspective and seeks to explore the contours of this emerging "education in." To this end, we conducted a comprehensive review of the existing literature on responsible technological innovation education. This analysis helped identify the key dimensions that structure this field, including content, pedagogical objectives, and curricular integration. Furthermore, several educational initiatives aimed at fostering a more responsible approach to technological innovation were identified, highlighting the diversity of existing practices.

Building on this theoretical analysis, the empirical component of our research focuses on how responsible technological innovation is concretely integrated into teaching practices. To shed light on these dynamics, we conducted semi-structured interviews with secondary school teachers. An interview guide, developed in alignment with insights from the literature review, was used to structure these discussions. Here, we present the initial findings of this study, offering insights into current classroom practices and the ways in which teachers incorporate responsible technological innovation into their pedagogy.

Key Words : Responsible technological innovation, Technological education, Teaching practices

1. INTRODUCTION

Technological education holds a legitimate place among school subjects, alongside scientific, literary, and artistic disciplines. While it is often associated with the scientific domain, it nonetheless stands out through its own distinct epistemology. For example, it has been noted that "normative aspects are intrinsic in technological knowledge" (De Vries, 2016), emphasizing that technology is not only concerned with understanding the world, but also with transforming it. This normative dimension, absent in science, is particularly embodied in manufacturing processes and established professional practices. Like other subjects that convey a form of culture—be it artistic, literary, or historical—technological education contributes to the dissemination of technical culture (Martinand, 2003). This culture helps students become familiar with technical objects and how they function, while also raising their awareness of the social, ethical, and environmental issues related to technological innovation. In France, this disciplinary field is structured along a continuum comprising three main stages: technology education in lower secondary school (collège), optional courses in grade 10 (such as Engineering Sciences and Technological Creation and Innovation), and, in grades 11 and 12, the STI2D track in the technological stream and the Engineering Sciences (SI) track in the general stream.

1.1. Innovation in French school curricula

Innovation now holds a significant place in the school curricula of technological education, reaching even the highest levels of educational governance. This positioning is notably illustrated by the evolution of the ministry's title itself: in 2017, the "Ministry of Higher Education" became the "Ministry of Higher Education, Research and Innovation," thereby establishing innovation as a strategic pillar of national education policy. This lexical choice resonates with European directives, such as the "Innovation Union" initiative launched in 2010 as part of the Horizon 2020 program.

In secondary education, the presence of innovation is also evident, particularly through several disciplinary titles. In lower secondary school, the official curriculum includes a section called "Design, *Innovation* and Creativity." In upper secondary school, innovation appears in no fewer than three disciplinary titles[1].

Yet, the place granted to innovation remains ambivalent. While it is indeed mentioned in the framework documents, it does not always translate into explicit and operational curricular objectives. It sometimes appears confined to the introductions of programs, without real implementation in the targeted competencies or strong alignment with assessment frameworks. In this sense, one might speak of a kind of "window dressing" of innovation, relegated to a symbolic rather than effective status. Paradoxically, we can observe that the notion of innovation itself—unlike its "symbolic halo" (Simondon, 2014)—is associated with

[1] SI-CIT : Sciences de l'Ingénieur - Création et **Innovation** Technologique (Optional course in Year 10)
IT : **Innovation** Technologique (Specialized course in Year 11)
2I2D : Ingénierie, **Innovation** et Dévelloppement Durable (Specialized course in Year 12)

applications such as intellectual property protection or logics of competitiveness and profitability, which still dominate the industrial world.

In fact, this presence of innovation in the curricula seems poorly aligned with the proclaimed aim of sustainability associated with notions such as sustainable development, social responsibility, and technological sobriety. This gap leads us to question more precisely the notion of **Responsible Technological Innovation** (RTI). We regard this term as relevant because it allows us to examine responsible innovation within secondary technological education—more specifically at the high-school level—without confining us to an overly rigid normative framework that would define its boundaries in advance. A possible starting point for this inquiry is therefore to begin by inventorying existing educational practices in this area, in order to better understand how this perspective is—or is not—reflected in technological teaching activities. To achieve this goal, we carried out the inventory along two main lines. The first focuses on practices already documented in existing literature, which we identified through a systematic review of the literature. The second line concerns actual practices on the ground, which we gathered through interviews with teachers of technical subjects. Our study aims to identify the actual practices of education for RTI implemented in real-world settings.

2. LITERATURE REVIEW

To conduct this inventory, a systematic interrater literature review was carried out to identify and characterise research focused on education for RTI. Eight databases were used, combining general sources (such as Scopus, Web of Science and Academic Search Complete) with specialised databases in the social sciences and education (PsycINFO, ERIC, Education Research Complete, GreenFILE and LISTA). Queries were based on the expressions "responsible innovation" and "responsible research and innovation", associated with the keywords "education", "school", and "teaching". This search strategy returned a total of 995 publications.

A selection process was then implemented, based on several exclusion criteria: language (only articles in English and French were retained), document type (peer-reviewed scientific articles), disciplinary scope (publications solely in the hard sciences were excluded; only articles in education sciences or engineering were retained), and the availability of full-text access. Following this screening, 42 articles were selected for qualitative analysis.

This analysis reveals that the majority of identified initiatives are implemented in higher or tertiary education. This observation highlights a significant lack of RTI integration in secondary education and suggests the existence of an educational blind spot in policies promoting responsible innovation education among younger learners.

The findings also indicate that several paradigms shape educational practices in relation to innovation, foremost among them the framework of RRI Responsible Research and Innovation (Stilgoe et al., 2013). This framework defines RRI action through four dimensions—anticipation, inclusion, reflexivity, and responsiveness—and was later expanded to encompass

seven dimensions: governance, public engagement, gender equality, scientific culture and science education, open access, ethics, and sustainability (Panciroli et al., 2020).

From a pedagogical perspective, several strong trends emerge. Project-based learning, serious games, and inquiry-based approaches are the most frequently used modalities. These approaches aim to foster active student engagement, enhance their ability to formulate problems, collaborate, and consider the ethical and social dimensions of technological objects. These objects play a central role in the educational settings, with a focus on two major categories: on the one hand, high-tech objects (robots, connected devices, autonomous vehicles, renewable energies); on the other hand, low-tech objects, used to question technological choices through the lens of sobriety, resilience, or accessibility.

Among the most structured initiatives identified, several programs stand out: African Solar Drive (Malan et al., 2017), Smart Grid (Hess et al., 2021), Ark of Inquiry (De Vries et al., 2017), HEIRRI (Higher Education Institutions and Responsible Research and Innovation) (Tokalić et al., 2021), PARRISE (Promoting Attainment of Responsible Research and Innovation in Science Education) (Levinson, 2018), and FuturesLabs (Conley et al., 2023). Cross-analysis of these projects reveals a set of recurring dimensions that structure an RTI educational framework:

- A clearly defined technical problem serving as a didactic entry point;
- An explicit curricular anchoring within official programs or targeted competencies;
- A central educational approach, often based on inquiry, research, or design thinking;
- External partnerships, involving researchers, businesses, non-profits, or local authorities;
- Activities designed to develop specific skills, both technical and transversal (collaboration, argumentation, anticipation);
- A dedicated learning environment (fablab, workshop, immersive setting, etc.);
- An applied research model closely tied to societal issues (energy, climate, inclusion, health, etc.).

The results of this literature review served as a foundation for constructing a semi-structured interview guide and a thematic analysis grid to systematically document existing educational practices related to RTI in secondary education, based on the perspectives of engineering science teachers.

3. METHODOLOGY

A series of semi-structured interviews was conducted with secondary school teachers of Engineering Sciences. In total, eleven interviews were carried out, representing a diversity of institutions, professional backgrounds, and teaching contexts. Teachers were recruited on a

voluntary basis and represent five institutions across two distinct regions. A simple coding scheme was adopted to identify the interviews; it combines the first letter (or, if necessary, the first two letters) of the teacher's institution with the interview's sequence number. This methodological choice was aligned with the exploratory aim of the study, which sought to understand how these teachers construct their representations of technological innovation, in its pedagogical, epistemic, and sociotechnical dimensions.

The use of semi-structured interviews is justified by the need to collect rich, nuanced accounts rooted in the teachers' professional experiences, while maintaining a common structure to ensure a minimum level of comparability across interviews. This interview format allows for a balance between participants' freedom of expression and thematic framing based on broad pre-defined categories derived from the literature review. It also enables the emergence of unanticipated themes, thereby allowing the refinement or expansion of initial research hypotheses.

2.1. Semi-structured interview guide

Dimensions constructed from the literature review detailed above served as the basis for the development of a thematic analysis grid. This grid was then used to design the interview guide, intended to explore how these dimensions are perceived, understood, and integrated by teachers into their pedagogical practices. The interview guide is structured into six main sections.

2.1.1. Presentation of the respondent

This first section aims to profile the interviewed teacher (educational background, years of experience, subject taught, specialisation). It allows contextualising responses and identifying possible generational effects, particularly in connection with reforms that have strengthened the teaching of technological innovation in the curriculum.

2.1.2. Technology, innovation, and technological innovation in official guidelines

The questions in this section explore teachers' perceptions of institutional expectations, the place of technology and innovation in curricula, and their familiarity with official guidelines (programs such as STI2D, SI-CIT, 2I2D, etc.). The objective is to compare these perceptions with lexical analyses of curricular documents and to determine whether teachers share a common or divergent understanding of the role assigned to innovation.

2.1.3. Definitions, understanding, and representations of RTI

This section examines the representations associated with concepts related to innovation (such as invention, progress, creativity) in order to explore conceptual confusions or nuances. It also investigates the ethical and social dimensions of innovation, the values underpinning educational projects, and how teachers perceive the influence of the technical objects used in class (high-tech vs. low-tech). Finally, sub-sections explore how teachers integrate the core pillars of RTI—stakeholder involvement, needs definition, design processes—into student projects.

2.1.4. Integration of RTI in teaching practices

Here, teachers are asked to describe a concrete activity they identify as related to RTI, which allows analysis of actual pedagogical practice. Questions focus on the methods used (project-based learning, inquiry-based approaches, etc.), the technical objects involved, the societal issues addressed, the involvement of external partners, and the assessment methods related to responsible innovation competencies.

2.1.5. From existing practices to the development of RTI resources

This section seeks to identify the resources currently used by teachers (documents, training, networks) and their needs in terms of training or tools to better integrate RTI into their teaching. It offers an overview of ongoing professional development practices and the expectations expressed by practitioners in the field.

2.1.6. Conclusion

Finally, the last section opens with more open-ended questions: programs or initiatives known by teachers that relate to RTI, obstacles encountered in pedagogical implementation (lack of time, vague institutional framing, student resistance, etc.). A final open question invites the teacher to freely share any element they deem relevant, thereby enriching the collected data beyond the anticipated framework.

2.1. Analysis

These interviews constitute a first phase aimed at informing and consolidating working hypotheses for a second research phase: the development of a questionnaire to be distributed on a larger scale to Engineering Sciences teachers. The topics explored in the interviews—such as definitions of innovation, preferred pedagogical methods, encountered obstacles, or intended educational goals—will serve as a basis for constructing this questionnaire, in line with a methodological logic of complementarity.

Once completed, the interviews were fully transcribed using voice recognition software, then manually reviewed and corrected to ensure the textual corpus's accuracy. Two types of analysis were conducted on the resulting corpus: first, a computer-assisted lexical analysis; and second, a thematic analysis based on a coding framework.

The lexical analysis was carried out using IRaMuTeQ (Interface for R for Multidimensional Text and Questionnaire Analysis), a free and open-source software based on the R statistical engine, particularly well suited to the automated analysis of large text corpora. The use of IRaMuTeQ is justified by its ability to apply robust statistical methods to explore the lexical structure of a corpus, especially in qualitative research seeking to objectify certain discursive regularities (Ratinaud & Marchand, 2012). Among these methods, the descending hierarchical classification identifies homogeneous classes of text segments by analysing word co-occurrences, without presupposing any a priori categories. This approach helps reduce interpretive biases linked to researchers' expectations, allowing lexical structures to emerge directly from the data.

The value of this method is twofold: on the one hand, it highlights dominant discursive trends within the corpus by identifying recurring semantic cores; on the other hand, it provides empirical support for structuring qualitative interpretation, offering a map of significant lexical usage. However, it is important to emphasise that the interpretation of the identified classes does not stem from the software itself, but from the researcher's analytical work.

4. RESULTS

4.1 Thematic analysis

The thematic analysis identified a total of seventeen educational initiatives focused on innovation. These initiatives are characterized by a wide variety of objectives and activities offered. Among them, a significant majority presents at least one feature that can be associated with the dimensions of Responsible Research and Innovation (RRI). Among the identified features, engagement and sustainable development are the most frequent. In terms of context, the majority of these initiatives (12 out of 17) take place exclusively in the classroom, without requiring any external interventions outside the school. The end-of-year project emerges as a key component, as it accounts for six out of the seventeen initiatives recorded. Additionally, a large proportion (9 out of 17) of the initiatives do not involve external partners, being entirely managed by the teacher. The way in which the activities are assessed is rarely detailed.

Table 1.
Devices described by teachers

Device	Technical Problem	Main Process	Space	Curriculum	Partners	RRI Dimensions
Bicycle Repair	How to maintain and repair a bicycle	Survey	Club within the school	Non-assessed, outside the school framework	None	Engagement, Sustainability
Blind Kayaker Guidance	Enable autonomous guidance for blind kayakers	Project	In class	Not mentioned	Blind kayaker	Inclusion, Engagement, Ethics
Boat Modeling	Introduce naval BTS	Design, realization	High school	Not mentioned	Naval BTS high school	Engagement
Christmas Decoration	How to showcase a Christmas village	Mini-project	In class	Not mentioned	Not mentioned	Engagement
City Planning	How to build a sustainable city	Project	In class, internet (Discord)	Assessed student involvement	Architecture school, Luanti community	Open access, Sustainability
Connected Greenhouse	Design an autonomous greenhouse with sensors/actuators and energy autonomy	Project	In class	STI2D senior project	None	Sustainability
Construction Site Visit, Bioclimatic House	Understand sustainable building design	Field visit	Construction site	Not mentioned	Building professionals	Sustainability
Crossing	Design a river crossing for a housing project	Feasibility analysis	In class	Not mentioned	Water damage researcher	Sustainability, Ethics
Fire Detection and Extinction	Detect and extinguish forest fires quickly with drones	Project	In class	Not specified	None	Sustainability Engagement
Measurement Tip	Design a measurement tip for a tachometer	Redesign	In class	Not mentioned	None	None
Name Tag	Allow quick reading of student name	Mini-project	In class, then students' homes	Not mentioned	None	Engagement

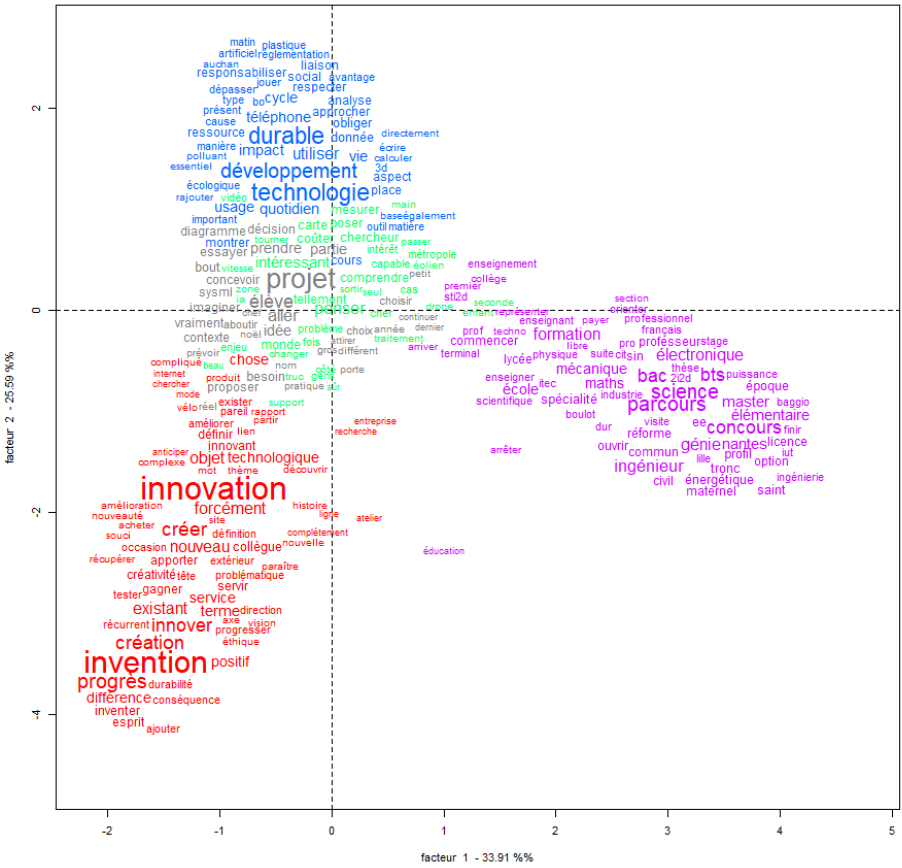
Optical Waste Sorter	How to improve waste sorting	Project, Survey	Internal school and external sites	Assessed participation and engagement	Waste landfill, incineration	Sustainability, Ethics, Governance
Pedagogical Radar	Encourage adherence to speed limits (30 km/h)	Design, realization	In class	Not mentioned	None	Governance
Sign Language Glove	Design a glove with sensors translating signs into speech and reverse mechanical hand	Project	In class	Not mentioned	None	Inclusion
Solar Tree	Light the school yard and recharge devices	Project	In class	STI2D senior project evaluation	None	Sustainability
Steam Engine Modernization	Modernize a steam engine with sensors and data processing	Project	In class	First-year STI2D project, innovation not assessed	None	Engagement
Visit to a Sorting Center	Identify sorting and recycling issues	Survey	External sorting center	Not specified	Local sorting center	Sustainability

4.2 Lexical analysis

Using Reinert's method, enabled by the IRaMuTeQ software, and analyzing the entire corpus consisting of eleven interviews, five distinct semantic classes emerged. The diagram below shows the distribution of these forms. By order of their share of the total forms in the corpus, the first class, shown in grey, focuses mainly on concepts related to the project and the student, representing 24.67% of the total forms. This class occupies a central position in the organization of the forms within the diagram. The second class, colored in blue, centers on themes of sustainable development and technology, accounting for 24.05% of the selected forms. The third class, in green and also located centrally in the diagram, represents 18% of the total forms and illustrates a more general theme strongly linked to concepts of organization and process. The fourth class, in red, specifically revolves around the lexical field of innovation, with terms like "invent", "creation", and "progress", representing 16.83% of the total forms. Finally, the last class, in purple, more isolated from the others, is characterized by institutional vocabulary, including terms such as "bac", "pathway", and "BTS", and accounts for 16.45% of the corpus forms. This organization highlights the priorities and concerns of the participants in relation to the educational and professional context.

Figure 1.

Reinert method diagram using IRaMuTeQ


facteur 2 - 25.59 %%
facteur 1 - 33.91 %%
innovation
invention
développement
technologie
projet
durable
créer
progrès
formation
mécanique
électronique
science
parcours
bac
bts
concours
ingénieur
génie
licence
master
élémentaire
maths
école
chose
objet technologique
innover
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durabilité
conséquence
inventer
esprit
ajouter
amélioration
nouveauté
acheter
souci
occasion
récupérer
créativité
tête
récurrent
progresser
différence
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saint
maternel
énergétique
civil
ingénieur
génie
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3d
calculer
écrire
directement
donnée
obliger
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analyse
cycle
type
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ressource
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essentiel
écologique
rajouter
vidéo
important
diagramme
montrer
tourner
essayer
prendre
partie
intérêt
chercheur
passer
outil matière
baseégalement
mesurer
main
quotidien
carte
poser
décision
couter
bout
vitesse
sysmi
zone
sortir
seul
cas
choisir
capable
éolien
petit
métropole
enseignement
concevoir
comprendre
penser
aller
élève
idée
monde
contexte
commencer
enseigner
lycée
physique
scientifique
spécialité
industrie
parcours
baggio
finir
option
civil
énergétique
maternel
saint
ingénierie
nouveau
collègue
apporter
extérieur
problématique
gagner
tester
direction
vision
éthique
positif
durabilité
conséquence
inventer
esprit
ajouter
amélioration
nouveauté
acheter
souci
occasion
récupérer
créativité
tête
récurrent
progresser
différence
définition
innovant
définir
améliorer
partir
rapport
parail
exister
support
réel
vélo
mode
proposer
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logic, illustrated by the modelling of a city carried out with the help of a community using open-source software (Luanti). These multiple dimensions—environmental sustainability, community engagement, social inclusion, and openness—strongly resonate with the principles of RRI. While it cannot be claimed that the identified initiatives constitute formal education in responsible technological innovation—especially since the teachers themselves do not describe them as such—it is nevertheless possible to assert that these initiatives contain its seeds. This observation highlights the importance of starting from the actual practices of field actors to consider guiding education in innovation towards a true education in responsible technological innovation.

Although teachers express strong support for partnerships with external actors, as evidenced by their statements ("*But I think that having a permeability between the outside and the school brings added value*" [teacher l3]), few concrete initiatives incorporating these collaborations are implemented. This situation can be explained by the increased complexity involved in designing and managing projects open to external collaboration, which require significant organizational and pedagogical investment. However, there is real potential to develop systems that encourage these collaborations, as shown by some initiatives reported in the literature, such as Ark of Inquiry (De Vries et al., 2017) and Engage (Pečiuliauskienė, 2019), which offer structured frameworks to facilitate the opening of teaching practices to external partners.

The interviews conducted reveal that innovation is generally not considered in teachers' evaluations. Several times, it appears that this exclusion is explained by the fact that innovation is not explicitly included in the official curricula. As one teacher points out:

"*Anyway, the program is called technological innovation, but there is none in it. Apart from telling them that this is a disruptive innovation, that is almost all there is in the program*" (Teacher b2).

Another teacher adds:

"*I was part of the jury, but I could not go against an official grading grid that does not take this dimension of innovation into account*" (Teacher l2).

Thus, the evaluation seems more focused on technical skills, at the expense of considering innovative aspects.

6. CONCLUSION

In conclusion, this research, which follows an initial bibliographic analysis, has allowed for a comparison between a collection of teaching experiences and the stated objectives of integrating responsible innovation into secondary technology education with the reality of pedagogical practices. It appears that while official curricula clearly emphasize innovation and highlight values related to social and environmental responsibility, the findings converge with previously observed results, revealing a significant gap between stated intentions and their actual translation into operational objectives. Numerous initiatives identified indicate that there is a favorable context for actions focused on education in responsible technological innovation. However, these initiatives remain largely informal and are minimally integrated into the

curriculum, except for the assessment of students' technical skills, due to a lack of institutional anchoring. Although this exploratory study is based on a limited set of interviews, it tends to show that genuine conditions exist for integrating education on responsible technological innovation into the curriculum. Support from existing mechanisms developed by field practitioners would be crucial to the success of such an endeavour. The main limitation of this study lies in the small number of teachers interviewed, which is insufficient to ensure data saturation. As this is an exploratory study, this limitation is not prohibitive; rather, it should primarily inform the design of the questionnaire for the next phase of the research. We also expect that, in the subsequent analysis, some findings will be confirmed, others qualified, and still others refuted.

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T/E DBBL Imposed Cognitive Demands: Computational Thinking Skills Required

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Abstract

In countries across the globe maintaining their economic competitiveness in the 21st century is increasingly dependent upon a population literate in the STEM disciplines and possessing the requisite capacity to utilize their knowledge (content and practices) and higher order thinking (critical and computational) for solving the complex social and technological problems of tomorrow. Historically the science, technology, engineering, and mathematics (STEM) fields of education have all lacked a sufficient body of empirical research demonstrating the positive cognitive outcomes derived from a technological/engineering design based learning (T/E DBL) approach. The theoretical premise underpinning T/E DBL is that learners will acquire habits-of-hand (designerly abilities) as a means for developing the habits-of-mind (designerly ways of knowing) needed to recognize and understand relationships between content and practice. As such, the pedagogical intent behind T/E DBL is to promote student understanding of the connections among disciplinary content and practices, and as a prerequisite for making informed decisions derived from that understanding (NAGB, 2008; Achieve, 2013).

As an integrative pedagogical approach T/E DBL has been shown to foster the development of targeted knowledge (content/practice) and higher order thinking (critical/computational) abilities (Shanta & Wells, 2022; Wells & Van de Velde, 2020; Wells, 2016). Largely absent, however, is authentic middle school classroom-based research empirically documenting the development of such knowledge and abilities; i.e., evidencing student achievement of workforce preparation goals. In the United States (U.S.) middle school Technology and Agriscience Education programs play a critical role in ensuring students have T/E DBL experiences intended to develop the knowledge and higher order thinking abilities they will need to solve the complex global problems in the coming decades.

The research presented in this paper involved a mixed method, pre/post-test design assessing the content/practice knowledge and cognitive demands (critical: informed decision-making and computational: sequential) imposed on a select group of U.S. middle school Technology and Agriscience students utilizing the STEMbot, a precision biotechnical robotics system, as part of their regular class curriculum. Findings indicate student engagement with the STEMbot as a T/E design based biotechnical learning (T/E DBBL) platform, resulted in gains in both targeted knowledge (content/practice) and higher order thinking abilities (critical/computational). Discussed are implications of such findings as indicators of strong connections between STEMbot T/E DBBL strategies and student development of targeted knowledge and cognitive abilities (critical/computational thinking) needed for making informed decision-making.

Keywords: Imposed Cognitive Demand | Technological/Engineering Design Based Learning | Critical Thinking | Computational Thinking | Informed Decision-Making

1. MOTIVATION

In 1983, nearly half a century ago, the National Commission on Excellence in Education (NCEE) published the report *A Nation At Risk: The Imperative for Educational Reform*. This report was instrumental in bringing the United States out of educational complacency by contending that in the face of increasing foreign competition it was losing its global economic dominance. The NCEE claimed in its opening sentences that "Our nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world" (p. 5). This report was challenging long standing national educational practices and calling for society, its people and schools, to become committed to achieving educational excellence. This educational challenge continues today, but with the added demand across all disciplines to incorporate integrative, design based learning approaches as the means to better prepare the STEM literate workforce (CPGE, 2007, 2010; Friedman, 2005; NGSS Lead States, 2013; NRC, 2014; Zhao, et al, 2021; Azizan & Shamsi, 2022). Meeting this challenge is critical not only in the U.S., but internationally as well given the projected direction of global workforce needs.

During the next decade the total employment in the U.S. economy is projected to have increased by 6.7 million jobs, of which roughly 3.5 million will be STEM-related jobs (U. S. Bureau of Labor Statistics, 2024). This reflects a 10.4% anticipated growth in STEM-related jobs over the next decade as compared to only 4.0% for all occupations (U. S. Bureau of Labor Statistics, 2025). At issue is that only about a quarter or less of all current college graduates are earning bachelor degrees in STEM fields (U. S. Department of Education, 2021; Cataldi, et al., 2014). These findings have spurred renewed research into the educational methods currently being used to prepare secondary school students, which has resulted in new understandings regarding the hurdles to growing a skilled STEM workforce. Specifically, cognitive research reveals that most middle school students "developed firm conceptions of their place in the broad social order and narrowed their vocational options accordingly" (Gottfredson, 2002, p. 99) prior to entering high school. In response to these findings, Career and Technical Education (CTE) developed national standards (NASDCTEc, 2012) designed to ensure all middle school students engage in CTE programs that address the growing demand for a skilled 21st century STEM workforce. Most states across the U.S. encourage or require middle school students (grades 6, 7, 8) to enrol in CTE exploratory programs such as Technology Education and Agriscience Education as a means for raising awareness of STEM career pathways, developing transdisciplinary knowledge, and acquiring both technical and cognitive skills relevant to pursuing those pathways. The empirical research necessary to substantiate the progress of these two exploratory programs toward addressing any of these workforce needs is lacking.

2. THEORETICAL FRAMEWORK

The inclusion of technological and engineering design based learning (T/E DBL) as a pedagogical focus in secondary education has long been advocated for to improve the teaching and integration of STEM subject areas (ITEEA, 2000; Wicklein, 2006; Schunn, 2008; NGSS Lead States, 2013; Denson & Lammi, 2014). Furthermore, there is increasing evidence that, as the great integrator (Wells, 2012), T/E DBL increases the potential to promote higher order cognitive skills (critical and computational thinking), and to teach targeted STEM content and practices (Hmelo-Silver, et al., 2000; Mehalik, et al., 2008; Katehi, et al., 2009; Jonassen, 2011; NAE/NRC, 2014; Wells, 2016, 2017, 2019). In particular, Technological/Engineering Design Based Biotechnical Learning (T/E DBBL), as a more transdisciplinary-focused integrative pedagogical approach, has been shown to improve student learning of STEM content and practices, and to foster their development of critical and computational thinking skills (Shanta & Wells, 2022; Wells, 2016). However, in spite of the growing evidence, inclusion of an integrative T/E DBL, and specifically T/E DBBL approach, is largely absent in middle school CTE programs throughout the U.S., and in several states in particular such as Virginia where middle school students are required to enrol in CTE exploration courses. Moreover, there is little in situ empirical research on T/E DBBL demonstrating student gains in STEM content and practices, improvement of transdisciplinary knowledge, or development of critical and computational thinking skills; i.e., evidencing student achievement of STEM workforce preparation goals. Empirical evidence of such achievement would be significant given cognitive research indicates that the middle school years constitute a pivotal developmental stage influencing the educational mind set and career directions of all students (Gottfredson & Lapan, 1997). Designed to be exploratory, experiential, and immersive, middle school Technology Education and Agriscience Education programs provide a critical pathway for ensuring that the students of today will enter the STEM workforce of tomorrow possessing the appropriate literacy levels and skills needed to support the U.S. economy.

Presented in this paper is the conduct of research intended to evidence the extent to which student engagement in T/E DBBL experiences as an integral component of their middle school Technology and Agriscience Education experience promotes the development of higher order cognitive abilities (critical/computational) and knowledge (content/practices) required of the 21st century workforce. The learning platform used to provide students with a T/E DBBL experience was the STEMbot. The STEMbot platform is a large-scale

Figure 1

STEMbot

(4'x7'x12') precision 3-axis gantry robotics system. This programmable Cartesian T/E DBBL robotics system (Figure 1) served as an instructionally flexible minds-on/hands-on learning platform immersing students in designing, implementing, and evaluating authentic biotechnical applications. A series of sequential instructional modules were developed to intentionally present students with the need for integrating STEM content and practices utilizing a variety of STEMbot tools, as well as other design technologies such as 3-D printers. In so doing, the STEMbot immersed students in a series of powerful, flexible design based teaching/learning experiences.

3. METHOD

The overarching goal of this study was evidencing improvement of critical thinking skills, computational thinking skills, and knowledge of targeted STEM (science, technology, engineering, and mathematics) content and practices among middle school technology and agriscience students as a result of their engagement in T/E DBBL using the STEMbot learning platform. As a curricular-embedded middle school experiential design based biotechnical learning approach, analysis of data gathered before, during, and after student engagement in the STEMbot modules offered answers to the following research question (RQ) and sub-questions (SubQ):

RQ: To what extent does engagement of middle school students in STEMbot T/E DBBL modules as part of their CTE exploratory program experience promote:

SubQ-1: Acquisition of targeted content and practices inherent to design tasks
SubQ-2: Critical thinking (informed decision-making)
SubQ-3: Computational thinking (sequencing)

The research design used to structure the investigation followed an exploratory convergent parallel (Quant + Qual) mixed method multiple case study approach. As part of a 9-week middle school Technology or Agriscience course, participants progressed through a series of nine STEMbot modules each of which engaged them in increasingly complex robotics tasks. Data were collected through a variety of measures designed to assess the level of participant content and practice knowledge, and their critical and computational thinking abilities.

3.1 Participants

Participants were grade 7 middle school students enrolled in either a technology education or agriscience education exploratory course in which the STEMbot system was one of several rotational components (stations) integrated into the curriculum. Such exploratory courses often adopt the station rotation approach to intentionally engage students in a broad spectrum of experiential learning opportunities. A total of 32 participants were drawn from both rural and urban schools (cases) in Virginia that utilized a station rotation curriculum, of which one station was the STEMbot.

Furthermore, middle school students were targeted for participation in this research given this age group is at a stage of developmental readiness for engaging in the increasingly complex problem-solving and conceptual thinking (Ching & Hsu, 2024; Ling et al., 2024) imposed by design based learning challenges presented through the STEMbot modules.

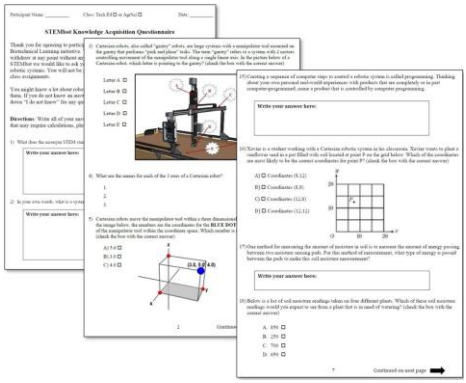
3.2 Measures

Four instruments were used to gather both quantitative and qualitative data. Quantitative pre and post data were gathered through the *Knowledge Acquisition Questionnaire*. As part of module completion, qualitative data were gathered through *Student Response Documents*, *Exit Tickets*, and *Verbal Feedback Reflections*.

3.3.1 Knowledge Acquisition Questionnaire

The Knowledge Acquisition Questionnaire (KAQ) was comprised of 31 items posing multiple choice and open-ended questions addressing tasks students completed in each of the modules (Figure 2).

Figure 2
Sample KAQ

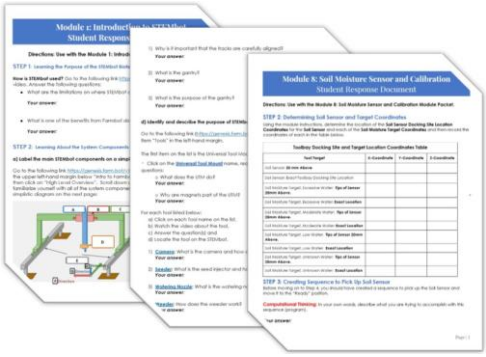

STEMbot Knowledge Acquisition Questionnaire

Twenty of the items were designed to elicit responses reflecting the types of knowledge (disciplinary content and practices) students were expected to have utilized and acquired through engagement with the STEMbot during completion of the first eight modules. Module 9 was created as a culminating, novel open-ended design challenge that imposed on students the need to utilize knowledge (content and practices) acquired in the previous eight modules. This body of knowledge would be necessary for engaging in predictive analysis and requisite of making informed decisions ultimately leading to a design that satisfied the solution criteria. Consequently, 10 items were designed specifically to assess the critical and computational thinking abilities imposed on participants throughout their completion of Module 9.

3.2.2 Student Response Document

Accompanying each STEMbot module was a digital response document posing questions for students to answer while they worked their way through completion of the eight modules (Figure 3). Questions were crafted to prompt students for targeted

Figure 3
Sample Student Response Documents

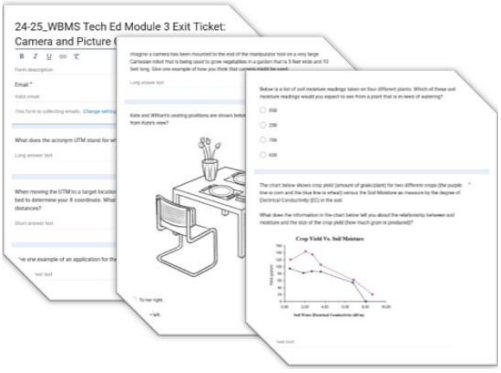


content or practice (procedural) knowledge posed by various STEMbot tasks as they progressed through a given Module. Responses entered on the document provided data demonstrating student use of the knowledge intentionally targeted in STEMbot tasks. Prompts also posed questions requiring students to recognize and exploit disciplinary connections (utilize transdisciplinary knowledge) essential for critical and computational thinking requisite to making informed decisions beyond the scope of tasks specific to the module.

3.2.3 Exit Ticket

At the completion of each module, students were presented with several exit questions (Figure 4). Exit ticket questions were designed to assess student knowledge regarding targeted content and practice inherent to some aspect of STEMbot manipulation during the completion of a Module. These questions were intended to assess the retention of key information needed for completing the next module. Additionally, as module complexity increased, the Exit Ticket questions posed were crafted to assess critical and computational thinking skills imposed on the learner as they were learning to use the system.

Figure 4
Sample Exit Ticket



3.3 T/E DBBL Intervention

The intervention was the integration of the STEMbot as a station rotation component of the middle school technology or agriscience curriculum. The intervention duration was the 9-week instructional period for a technology or agriscience education course.

3.3.1 Instructional Modules

STEMbot modules are digital web-based documents housed in a Google Classroom. The Google Classroom was one created and managed by the teacher and used as the instructional portal for all of their technology and agriscience classes. A series of eight instructional modules challenged students with manipulating the large-scale precision robotics system within a Cartesian coordinate plane to autonomously perform biotechnical tasks addressing increasingly complex design problems. The eight modules (Figure 5) were designed to be sequential, with skills and knowledge acquired in one module necessary for completing tasks in the next. In this way students acquired basic skills and techniques necessary for controlling the movement of the STEMbot gantry along Cartesian coordinates within the 3D space of the raised bed (Figure 6). Movement was based on sequencing programs students created for first positioning the universal tool mount (UTM) located at the lower extremity of the Z axis to grasp various external tools (Figure 7) from the tool bay and then utilize them at various 3D locations within the raised bed to perform tasks such as planting, soil sensing, watering, and imaging.

Figure 5

Sample Module

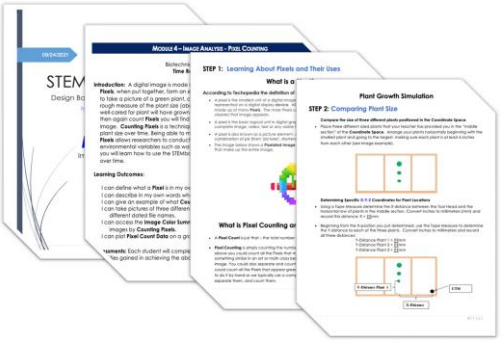


Figure 6

STEMbot Gantry & Raised Bed

Figure 7

STEMbot Tools

3.3.3 Implementation

The research reported was conducted over a 9-week instructional cycle (marking period). At the start of the 9-week marking period and before participant engagement with the STEMbot, the

Knowledge Acquisition Questionnaire (KAQ) was administered to participants as a quantitative pre-assessment.

During weeks 2 through 9, participants engaged with the STEMbot DBBL robotics system for approximately 45 minutes each day (~3.75 hours/week) to complete all eight modules. When completing each STEMbot module, students entered their responses directly onto an accompanying *Student Response Document* using their school-issued Chromebook. All modules concluded with students responding to a set of *Exit Ticket* questions assessing the knowledge (content and practice) and abilities (critical/computational thinking) students were to have acquired as a result of completing a given Module. At the conclusion of the 9-week instructional cycle the KAQ was administered online to participants as a post-assessment. Student participation in the STEMbot project ended with completion of their 9-week Technology or Agriscience Education class.

4. RESULTS

4.1 Quantitative Analyses

Following completion of all eight STEMbot modules, quantitative analysis of data gathered from the pre and post administrations of the KAQ allowed for the comparison of means regarding changes in student content and practice knowledge, as well as their critical and computational thinking abilities.

Table 1

Pre/Posttest KAQ: Participant Mean Scores

	M	***SD***	***SEM***	***df***	***t***	***p***	**†d**
Pre	33.94	20.35	3.60	31	17.99	0.0001*	2.59
Post	89.06	22.22	3.93				

Note. $n = 32$ *$p < .05$, two-tailed, paired; †Effect Size (Cohen's D)

Analysis of the 32 participant mean scores on the KAQ (Table 1) indicates significance for pretest/posttest differences ($p < .05$), with the practical strength of this mean difference substantiated by the large effect size (d = 2.59). This analysis indicates that participant engagement with the STEMbot modules led to an overall increase in targeted knowledge and higher order thinking abilities across all participants.

Table 2

Pre/Posttest KAQ: Aggregate Mean Scores All Items

	M	*SD*	*SEM*	*df*	*t*	*p*	†d
Pre	1.60	1.34	0.24	30	6.42	0.0001*	0.71
Post	2.87	2.11	0.38				

Note. $n = 31$ *$p < .05$, two-tailed, paired; †Effect Size (Cohen's D)

Analysis of pre/post aggregate mean scores for all 32 KAQ items (Table 2) indicates significance for pre/post differences ($p < .05$), with the practical strength of this mean difference substantiated by the large effect size (d = 0.71). These results indicate that following completion of all eight STEMbot modules, participant scores across items demonstrated overall gains in both targeted knowledge and higher order thinking abilities.

Pre/post analysis of disaggregated items was conducted to discern differences specific to knowledge versus computational thinking abilities (Tables 3 and 4 respectively).

Table 3

Pre/Posttest KAQ: Mean Scores Content/Practice Items

	M	*SD*	*SEM*	*df*	*t*	*p*	†*d*
Pre	1.67	1.43	0.31	20	6.75	0.0001*	0.85
Post	3.30	2.29	0.50				

Note. $n = 21$ *$p < .05$, two-tailed, paired; †Effect Size (Cohen's D)

Table 4

Pre/Posttest KAQ: Mean Scores Computational Thinking Items

	M	*SD*	*SEM*	*df*	*t*	*p*	†*d*
Pre	1.46	1.20	0.38	9	2.61	0.029*	0.40
Post	1.98	1.38	0.44				

Note. $n = 10$ *$p < .05$, two-tailed, paired; †Effect Size (Cohen's D)

Analysis of disaggregated means revealed significance ($p < .05$) for pre/post differences in those KAQ items specifically targeting content and practice, and those targeting critical and computational thinking abilities. The practical strength of the differences in means for the content/practice items is substantiated by a large effect size (d = 0.85), and by a moderate effect size (d = 0.40) for the computational/critical thinking items. These findings indicate student engagement with the STEMbot while

completing all eight modules resulted in improved content and practice knowledge, and critical and computational thinking abilities.

4.2 Qualitative Analyses

Quantitative analysis of pre/post KAQ responses alone supports the hypothesis that student engagement in T/E DBBL results in improved knowledge and higher order thinking abilities. However, analysis of qualitative data was used to further substantiate the claim by corroborating the quantitative results.

4.2.1 Student Response Documents

Each STEMbot Module is set up as a series of increasingly complex tasks students complete as a means for learning how to manipulate and direct the gantry system. This includes learning the names and functions of robotic components, manoeuvring the system within a 3D space, utilizing the Universal Tool Mount (UTM) to retrieve and use various tools (planting, watering, soil sensing, imaging, etc.), and creating sequences (programs) to accomplish increasingly complex biotechnical procedures.

While completing the tasks within a given module, students used a separate digital *Student Response Document* (Figure 4) for responding to questions, or to enter data gathered during their use of a tool. The goal of each module was to have students successfully demonstrate their ability to fully utilize the gantry robotics systems. To help ensure all students acquired these abilities while completing a Module, they had the option of repeating a task any number of times until they were successful in completing it. Point values were assigned to every entry on each STEMbot Module *Student Response Document*, which when analysed provided an assessment of student performance on all Modules.

Table 5

Mean Scores: Module Student Response Documents

	Modules							
	#1	***#2***	***#3***	***#4***	***#5***	***#6***	***#7***	***#8***
Mean Score (%)	86	90	98	80	86	85	95	88

Analysis of entries made on *Student Response Documents* for each Module found student scores to be very high (Table 5) as was intended and expected given they could repeat any/all steps until successful. These findings indicate participants were demonstrating targeted knowledge and abilities directly aligned with the assessment items on the pre/post KAQ.

In addition to questions prompting student demonstrations of content and practice knowledge, Modules contained several open-ended questions intended to elicit demonstrations of specific computational thinking (CT) skills (abstraction, algorithmic, decomposition, debugging). Table 6 presents results from the analysis of responses to these questions for each module.

Table 6

Computational Thinking Items: Mean Scores

	CT Item Mean Score (%)/Module								
CT Skills	***#1***	***#2***	***#3***	***#4***	***#5***	***#6***	***#7***	**#8**	***M***
Abstraction	80	80	⊗	63	70	83	100	46	75
Algorithmic	40	11	⊗	70	85	55	90	80	62
Decomposition	⊗	⊗	⊗	85	⊗	63	100	50	75
Debugging	⊗	⊗	56	100	95	63	97	94	84

Note: ⊗ = no items included for that Module

It is important to note that the degree of complexity in tasks students must perform increases in each successive Module. In this context of increasingly complex tasks, analyses of responses to the CT items within *Student Response Documents* for each of the Modules indicates that on average, students were progressing in their development of CT skills the more they engaged with the STEMbot. This is particularly evident in the mean CT scores for Modules 7 and 8 – the most complex ones.

4.2.2 Exit Tickets

Every module ended with the same prompt instructing students to finish the module by submitting an *Exit Ticket* (Figure 4). The *Exit Ticket* was a separate online digital document comprised of a set of questions developed to assess the content/practice knowledge and critical/computational thinking abilities students were to have acquired as a result of completing a given Module. Furthermore, questions on the *Exit Ticket* were the same knowledge and abilities questions as on both the *Student Response Document*, and the pre/post KAQ.

When completing the *Exit Tickets* students did not have access to their previously submitted *Student Response Documents*; i.e., student *Exit Ticket* responses reflected the extent to which they could demonstrate targeted learned outcomes following completion of a given STEMbot Module.

Table 7

Mean Scores: Module Exit Ticket Responses

	Modules							
	#1	***#2***	***#3***	***#4***	***#5***	***#6***	***#7***	***#8***
Mean Score (%)								
100-90	62	14	41	25	38	29	0	7
89-80	24	25	14	29	28	26	28	7
79-70	5	19	5	7	3	6	13	3
69-60	3	8	11	7	6	10	6	30
59-50	3	3	3	0	3	0	13	13
49-40	0	14	3	4	3	3	22	7
39-30	1	3	0	7	3	10	13	17
29-20	0	8	3	14	3	10	3	7
19-10	0	0	5	7	13	3	0	10
9-0	0	0	14	0	0	3	3	0

Exit Ticket response data displayed in Table 7 show a preponderance of scores falling within the 100 to 70 percent range for Modules 1-6 (on average 66% of students earned passing scores). Scores for Modules 7 and 8 were more widely dispersed across all ranges and *Exit Ticket* scores were markedly lower than scores on the first six modules. This is not surprising given Modules 7 and 8 were the most complex modules, and imposed higher cognitive demands.

4.2.3 Mixed Method Analysis

From a research standpoint it is important to note that the set of 31 questions on the pre/post KAQ were drawn from questions posed in both the *Exit Tickets* and the *Student Response Documents*. In this way the same items were used for assessing targeted knowledge (content/practice) and higher order (critical/computational) thinking before, during, and after the intervention.

Quantitative analysis of *Knowledge Acquisition Questionnaire* (KAQ) data previously presented in Table 1 indicates significance for overall pre/post mean differences ($p < .05$) in participant gains of targeted knowledge and higher order thinking following the intervention. The practical strength of these overall mean differences is substantiated by a large effect size ($d = 2.59$). Aggregate item analysis (Table 2) indicates significance in pre/post mean differences ($p < .05$) with a large effect size ($d = 0.71$) substantiating the practical strength of these differences. Furthermore, analysis of

disaggregated content/practice and critical/computational items (Tables 3 and 4 respectively) indicates significance in pre/post mean differences ($p < .05$) for both sets of items, each of which are substantiated by a large to moderate effect size ($d = 0.85$ and $d = 0.40$ respectively). Overall, the quantitative analysis of pre/post KAQ data implies that the intervention, STEMbot T/E DBBL, promoted gains in student knowledge and higher order thinking abilities.

Qualitative analysis of entries made by participants on the *Student Response Documents* (Table 5) indicates demonstration of high performance abilities when utilizing the gantry robotics systems throughout completion of the STEMbot modules. Analysis of the open-ended questions (Table 6) specifically targeting computational thinking (CT) skills (abstraction, algorithmic, decomposition, debugging) shows students progressing in their development of CT skills as they progressed through the sequence of Modules. These qualitative findings corroborate the quantitative results of KAQ data analysis.

At the conclusion of each Module students completed an *Exit Ticket* posing questions designed to evaluate the extent to which the targeted content/practice knowledge and critical/computational thinking abilities had been acquired. Qualitative analysis of *Exit Ticket* responses (Table 7) indicates for Modules 1-6, approximately two thirds of students (66%) earned passing scores; i.e., demonstrated achievement of targeted learning outcomes. And for Modules 7 and 8 which were the more complex modules and imposing higher cognitive demands, a slightly lower percentage (58%) were able to earn passing scores. These qualitative findings corroborate the quantitative results of KAQ data analysis.

5. 5. DISCUSSION

The impetus for this research was to address the lack of a sufficient body of empirical research demonstrating the positive cognitive outcomes resulting from student engagement in technological/engineering design based biotechnical learning (T/E DBBL). More specifically, this research addresses the need for empirical research conducted in the authentic context of the middle school classroom documenting the positive cognitive outcomes resulting from student engagement in T/E DBBL.

To that end, results from this mixed method study provide convincing empirical evidence demonstrating the potential of a T/E DBBL pedagogical approach for promoting acquisition of targeted knowledge (content/practice) and higher order thinking (critical/computational) abilities among grade 7 middle school participants. Adhering to this pedagogical approach, the STEMbot provides middle school educators with an instructional platform that immerses young learners in a designerly method for acquiring and then using knowledge requisite of making informed

decisions. Learners able to employ the designerly knowledge acquisition heuristic (KAH) (Wells, 2021) as a means for coming to know, demonstrate better understanding of transdisciplinary concepts presented through T/E DBBL.

Prior cognitive research has recognized that during the middle school years most students develop their sense of place in the social order and narrow their career directions accordingly (Gottfredson, 2002). Middle school exploratory programs such as Technology Education (TE) and Agriscience (AgSci) Education offer students experiential pathways for promoting the knowledge and cognitive abilities requisite of the 21st century STEM workforce. Findings from this research imply that integrating the STEMbot platform into the regular TE and AgSci curricula provides students with experiences that promote their acquisition of the technical and cognitive abilities needed for their future participation in the STEM workforce.

The research presented reflects results from a small mixed method study which would be transferable only to those middle school sites integrating the STEMbot platform. Needed are additional studies utilizing similar T/E DBBL platforms and curricula designed to intentionally impose the need for targeted STEM content and practice knowledge and the higher order cognitive abilities requisite of informed decision-making. Moreover, further research is needed to investigate what unique teaching strategies educators utilize while implementing T/E DBBL shown to promote such informed decision-making. Investigations such as these conducted in the middle school classroom context will advance the growing body of empirical research demonstrating the positive cognitive outcomes from student engagement in T/E DBBL.

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Decoding Design Thinking: Common Threads for Technology Education

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Abstract

The integration of design as a fundamental aspect in technology education curricula is evident worldwide, though the terminology varies across different contexts. The term design thinking is widely used to describe a framing of the design-related activity within this field; however, other terms exist and interpretations of what these encompass differ. Various frameworks exist to describe or explain the components of design, each offering unique perspectives and emphasising different aspects of the process. Despite its growing prominence, there remains a lack of consensus regarding the terminology and exact nature of design (thinking, process, framework), which creates challenges in both its implementation and assessment within educational settings. The explicit inclusion of *design thinking* in curricula, along with its lack of explanation, highlights the need for a clearer, more comprehensive understanding of the concept, as well as similar concepts. These differing phrasings and viewpoints leave an ambiguity on what design thinking entails, making it difficult to investigate its associated skills when their definitions remain uncertain. Without a well-defined and commonly accepted framework, meaningful connections between design thinking and broader educational goals cannot be effectively explored.

Given the existence of multiple design frameworks, this paper seeks to identify commonalities among them and pinpoint shared components and points of departure across different design thinking models. A rapid review was conducted to examine the nature and application of design thinking frameworks in technology education in recent years. The findings provide an overview of these frameworks, with a more detailed focus on key components that frequently emerge. Ultimately, this paper contributes to a broader understanding of design thinking by highlighting its core components, shared principles, and implications for technology education.

Key Words: Design thinking, Spatial thinking, Design framework.

1. INTRODUCTION

The importance of design in technology education is well established (Baynes, 2006; Stables, 2008) and can be seen as a fundamental aspect of the subject area. Design education is an area of continuous growth and a core element of technology education internationally (McDyer et al., 2024). In Ireland, technology education curricula has placed explicit emphasis on design throughout the entire suite of technology subjects with the terms *engineering design process*

(NCCA, 2019b), *design thinking* (NCCA, 2019c, 2019d), and *design and innovation* (NCCA, 2019a) being included within the Junior Cycle (lower secondary) curricula. In senior cycle (upper secondary) curricula, the use of a *design based approach* can be seen in the subject of Technology (NCCA, 2007b), the explicit use of design in the title of *Design and Communication Graphics* as well as throughout its curriculum document (NCCA, 2007a), as well as through the clear emphasis on design and design capability being placed within the currently redeveloping subjects of Construction Technology (NCCA, 2025a) and Engineering (NCCA, 2025b).

However, a common discussion in the field is how complex and challenging it can be to teach design as it is seen as a messy activity with many unknowns and many eventualities (Baynes, 2006; McDyer et al., 2023). One method used to ease this pedagogical difficulty is the employment of a framework that supports pedagogical implementation, by providing a better understanding of what design looks like, and what design can include within an educational environment. The problem however arises when a term such as *design process* or *design framework* is linked to many different interpretations, leading to an issue of conceptual ambiguity. Even within the field, different models of design processes such as (1) *empathy*, *define*, *ideation*, *prototype*, *test* (Balakrishnan, 2022), (2) *define, learn, plan, try, test, decide* (P. D. A. Putra et al., 2023), (3) *identify the problem*, *determine the solution*, *design a model*, *make a model*, *recreate a model* (M. J. A. Putra et al., 2023), and (4) *ask*, *imagine*, *plan*, *create*, *improve* (Samad et al., 2023) can be seen. In contexts where numerous interpretations or methodologies exist, such as in the discourse surrounding design thinking, teachers may experience a form of choice overload (Chernev et al., 2015; Schwartz, 2015) leading to uncertainty, confusion, and decision paralysis. The development of an individualisable guiding design framework, although important, is not something achievable until the trends within current design processes are first examined. This study aims to review and synthesise common components of design processes evident in the literature, to provide an overview of varying techniques and compile commonalities for further review.

2. METHOD

A rapid review (Grant & Booth, 2009) was conducted to gain insight into the various interpretations of design processes that were being employed within the literature. Two databases, SCOPUS and Web of Science were employed for the study. With the nuanced wording of design activity in the literature the base words *design,* and *creativity* were used alongside the base words *capability*, *competency*, *ability*, and *literacy* to build the search. For the wording of the activity, words such as *framework*, *model*, *tool*, and *structure* were used. The full list of terms can be seen in the Boolean search string below. For the feasibility of the rapid review, the search was limited to articles in English that were published within five years (2021-2025 inclusive). The search was conducted on the 29/5/2025 and as such only articles published before that were included.

The following search term was used for SCOPUS: TITLE (("design*" OR "creativ*") AND ("Think*" OR "capabil*" OR " competenc*" OR "abil*" OR "liter*") AND ("framework" OR "model*" OR "tool" OR "structure" OR "paradigm*" OR "method*" OR "process*" OR "component*" OR "element*" OR "dimension*" OR "stage*" OR "phase*" OR “review”)) AND

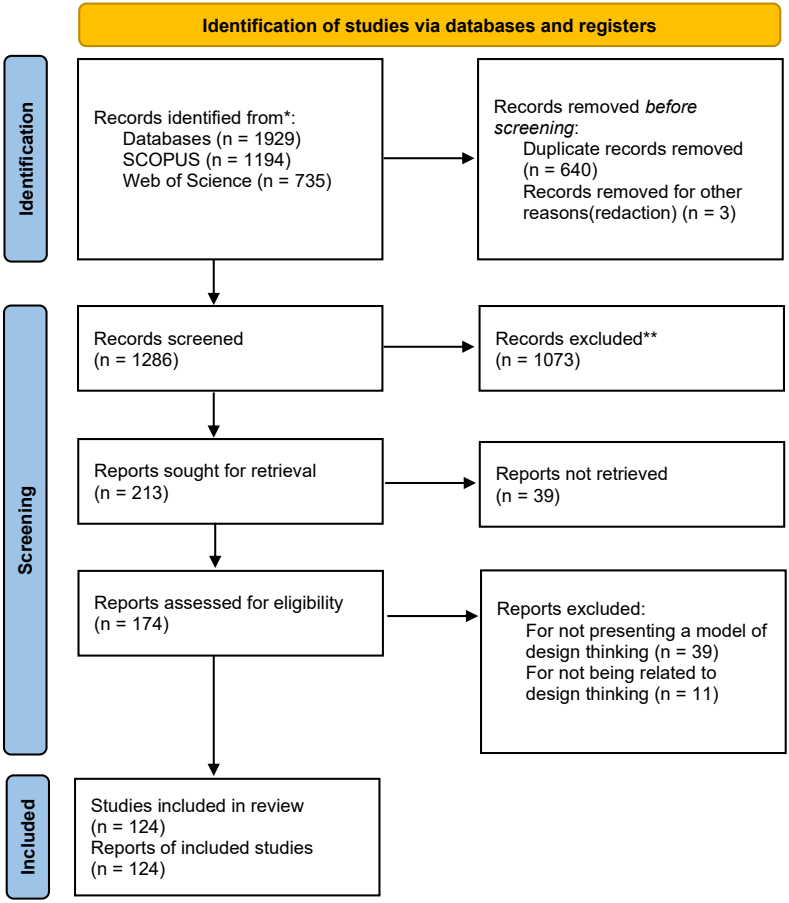
PUBYEAR > 2020 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")).

The following search term was used for Web of Science and the same limitations as above were included: TI=("design*" OR "creativ*") AND TI=("Think*" OR "capabil*" OR " competenc*" OR "abil*" OR "liter*") AND TI=("framework" OR "model*" OR "tool" OR "structure" OR "paradigm*" OR "method*" OR "process*" OR "component*" OR "element*" OR "dimension*" OR "stage*" OR "phase*" OR "review").

The initial search resulted in 1194 articles from SCOPUS and 735 articles from Web of Science which can be seen in the PRISMA flow process (Moher et al., 2009) shown in Figure 1. Duplicate articles were removed and from the 1286 remaining articles 130 were randomly selected and separately screened by two of the authors (First and Last authors) for relevance to the study. Screening was conducted by review of the title and abstract. Interrater reliability of 80.6% was achieved which was deemed satisfactory for the screening to continue. The remaining articles were screened and 213 were then sought for retrieval, of which 174 full texts were found. The full texts of these articles were then screened for eligibility on the basis that they employed, discussed, or devised and model of design. Thirty-nine were removed on the basis that they did not include any reference to a model of design and 11 were removed on the basis that although design may have been mentioned, the paper used this to frame another construct.

When examining the remaining corpus to establish trends, the term ‘component’ was specifically chosen by the authors to describe the commonalities in the research. Although this is used in some of the literature examined, it is important to note that this was chosen as meaning-neutral term by the researchers, as the components identified within the literature varied from more practical in nature to that of values and beliefs. ‘*Component’* offers a non-suggestive grouping term for the results found.

Figure 1.
Prisma flow process



3. FINDINGS

From the review of the included articles, it became apparent that there are a lot of similarities in the models being used with many using the same model, or a differently named model with the same components. The reporting of these models differed with even the components themselves

being named differently among studies, the most common terms used included *stage*, *phase*, or *step*, but all terms used can be seen in Table 1. Similarly, a clear trend could be seen in the term used for the process (e.g. design thinking), with a strong emphasis on the use of *design thinking*, other terms used can be seen in Table 2.

Table 1.
Component names as found in the literature

Terms for Components	Frequency
Stage	56
Phase	41
Step	41
Component	4
Principle	4
Action	2
Theme	2
Attribute	2
Characteristic	1
Concept	1
Activity	1
Element	1
Procedure	1
Mindset	1
Skill	1
Practice	1
Competency	1

Table 2.
Model terms as found in literature

Terms included in multiple models	Frequency
Design Thinking	132
Engineering design process	9
Double Diamond	9
Sprint	5
Creativity	3
Design process	2
Problem-Solving	2
DT-PBL	2
Unique model names	
We!Design!ForSTEAM	
6E Model	
four phases model CPSBM	
innovation guide	
IDEO Model	
designing activity	
Biodesign process	
Human-Centred Design	
Xinjiang brocades innovative design model based on DT	
DRIIPT instructional design process	
VLEEDP model	
DTAIL Model	
Three gear framework	
Knowledge funnel	

EDP-CDIO
DT-QLCA
Room2Educ8 framework
KE-DT
Design competence framework

The components identified within the literature were all framed around something that can be developed within a person engaging in technology education. Some of these component are linked to technical skills and procedural development while others are linked to human traits and attitudes which can be developed through engagement with the process.

The use of the term *design thinking* is widely seen within the literature, with the majority of studies implementing a version of *empathy*, *define*, *ideate*, *prototype*, *test* (c.f. Balakrishnan, 2022; He et al., 2023; Nguyen et al., 2024). This five-stage model can be seen widely implemented in design settings where the components are used to guide the design process. This however isn't the only process found when examining *design thinking* models. Other models that can be seen include the five-stage model of *exploration*, *interpretation*, *ideation*, *execution*, *reflection* as described by Aris et al. (2025) and a three-stage model can of *exploratory*, *ideation*, *experimentation* can be seen from Fu et al. (Fu et al., 2024). When the search term is changed to that of *design process* we see even more variance from the four-stage model of *problem scoping*, *developing alternative solutions*, *project realisation*, *iteration* (Osgood & Johnston, 2022), to the five-stage model of *asking*, *imagining*, *planning*, *creating*, *improving* (Sopakitiboon et al., 2023), and even to a seven-stage model of *project identification*, *specification development*, *conceptual design*, *detailed design*, *delivery*, *service maintenance*, *retirement / redesign* (Mahajan et al., 2021). Although this review further highlights the differences observed within research on design, some patterns within the components can be seen which will be discussed in the qualitative synthesis below.

4. QUALITATIVE SYNTHESIS

From examining the literature and the grouping of components evident in design processes, two levels can be seen to emerge. The first level that can be seen is that of a technical nature central to the process of designing, the second level is linked to that of human values and capabilities, also central to the process of designing, but not easily seen as an externalisation of the designer. The six technical components are: *Framing the Design Challenge*, *Investigating and Exploring*, *Generating and Developing Ideas*, *Making and Implementing Solutions*, *Assessing and Validating Solutions*, and *Iteration and Enhancement.* The five value and capability components are: *Understanding Users and Perspectives*, *Collaborative Engagement*, *Reflecting and Reframing*, *Cultivating Design Values and Awareness*, and *Communicating and Sharing Design Work*. As a large number of terms were identified, only a small number have been included as examples in this paper. It is important to note that the frequency does not correlate with any level of importance, all terms were treated as equally weighted. It is also important to note that some terms fit within more than one component due to original authors description of each term. Due to the scope of this paper, only the technical components will be discussed in detail.

4.1. Component Overview

4.1.1. Framing the Design Challenge

This component is centred around the identification of the problem at hand, often seen in the literature as the term *define* (c.f. Balakrishnan, 2022; P. D. A. Putra et al., 2023; Tridalestari et al., 2021) although many other terms are used. This component deals with gathering information on what the problem is, or setting a problem, depending on the context it is applied in. In a more open-ended design process, a designer may have to first define a problem themselves whereas in a more closed or hybrid process the problem may be provided as a starting point. The activities that manifest as a part of this component include clustering, creating personas (Au & Goonetilleke, 2025), defining what success looks like (Ozsoy & Mengüç, 2024), and trying to understand who will be affected (Frisk & Bannister, 2022). Some of the literature terms included in this component are:

- Problem identification
- Problem scoping
- Solution definition from the point of view of all stakeholders
- Diagnosis
- Need finding
- Define
- Analysis
- Focus

4.1.2. Investigating and Exploring

This component is based on research and information gathering activities that provide insight into possible solutions. It deals with using external sources to gather whatever information is necessary to support the design process. This may manifest as market surveys (Yang & Man, 2021), interviews or observations (Frisk & Bannister, 2022), or conducting focus groups (Viviani et al., 2024), but the research process will differ depending on the context of design. Some of the literature terms included in this component are:

- Discover
- Data gathering
- Ask
- Exploration
- Research
- Grasping external knowledge
- Interpret
- Interpretation
- Observation

4.1.3. Generating and Developing Ideas

This component is focused on the creation of initial concepts and preliminary ideas. These ideas are not expected to be the final solution but rather an important step in ruling out sub optimal suggestions. In the literature this is most commonly referred to as *ideate* (c.f. Lynch et al., 2021; Magdalenić & Luić, 2025; Moffett & Cassidy, 2023) or *ideation* (c.f. Alvarado, 2025; Quattrini et al., 2025) and manifests in activities such as brainstorming (Viviani et al., 2024), stimulating questions (Liudmyla et al., 2022), and sketching a model (Aris et al., 2025). Some of the literature terms included in this component are:

- Solution development
- Ideate
- Visualisation and sense making
- Idea testing
- Experimentation
- Produce ideas
- Develop
- Design

4.1.4. Making and Implementing Solutions

This component focuses on the further development of the initial ideas, creating physical prototypes and models for further critique and refinement. It is separated from *generating and developing ideas* as it deals with the construction of something physical. In the literature this is most commonly referred to as *prototype* (c.f. Detera & Hanbal, 2024; Yedra & Aguilar, 2022; Zhao et al., 2025) and manifests in activities such as building user interfaces (Jurry & Rinda Nur, 2024) and creating physical models (Kweon & Park, 2023; M. J. A. Putra et al., 2023). Some of the literature terms included in this component are:

- Prototype
- Design a model
- Implementation
- Detailed design
- Elaboration
- Create
- Execution
- Making it tangible
- Try

4.1.5. Assessing and Validating Solutions

This component deals with the critique of proposed design solutions in the context of their intended purpose. Most commonly referred to as *test* (c.f. Gong et al., 2022; Kweon & Park, 2023; Yam-Ubon & Thongseiratch, 2023)this component manifests in activities such as gathering feedback from intended users (Yam-Ubon & Thongseiratch, 2023), and creating user questionnaires (Fuada et al., 2024).Some of the literature terms included in this component are:

- Design testing
- Idea evaluation and selection
- Solution validation
- Select an optimal solution
- Try it out
- Assessment
- Delivery

4.1.6. Iteration and Enhancement

This component is based on the idea of a cyclical approach to design, where the design re-engages with the design process to improve on the created concepts. This component was not widely seen as part of models presented but nonetheless this manifests as the rebuilding/alteration of models created based on performance in an associated evaluation (Galanti & Holincheck, 2024; Xi et al., 2024).Some of the literature terms included in this component are:

- Recreate a model
- Improving
- Test and evolution and active experimentation
- Redesign, rebuild, and retest
- Improve
- Make it better

4.2. Proposed Model

The proposed model of design components as identified from the literature includes the 6 technical components, and the 5 value and capability components combined. It is intended that there is a level of permeability of the values and capabilities into all of the technical components. Such a component as *collaborative engagement* for example cannot be limited to a *stage* or *step* but rather this is something that should be immersed in the entire design process. It is important to note that this is not a prescribed list of steps, or even an order of progression, and a designer may enter or exit the process as they see fit. The proposed model simply encompasses commonalities among design processes as seen in the literature to offer a holistic view of design components and provide insight to educators and researchers alike on the common aspects of design.

5. FUTURE CONSIDERATIONS

The findings and qualitative synthesis within this literature review offer an insight into common components within frameworks of design such as *design thinking*, the *engineering design process*, and various differently named processes. Further work is needed to define and discuss the value and capability components proposed and further examination of all components is needed to determine the suitability of the model for a design setting within technology education. With future development of this model, a basis may be provided for educators as well as curriculum

makers to examine what a common design process might entail, supporting the integration of design within technology education classrooms and curricula.

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The Current status of technology attitudes among primary, middle and high school students——Based on empirical survey of 11,480 students from 18 provinces in China

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Abstract: Since the dawn of human civilization, technology has permeated every aspect of our lives, transforming how we dress, eat, live, and travel. The 21st century has witnessed a new wave of technological revolution and industrial transformation, driven by innovations like the internet of things, artificial intelligence, quantum communication, 5G networks, blockchain technology, renewable energy, and autonomous vehicles. These developments are reshaping global economic landscapes, cultural paradigms, and lifestyles. The essence of our technological era has undergone profound evolution, demanding not only basic life skills but also a proactive technological mindset aligned with industrial upgrading and technological progress. Therefore, investigating the current state of technological attitudes among Chinese citizens in this new era holds significant value and has become a crucial academic focus.

Currently, research on public technology attitude measurement in China remains relatively underdeveloped, with no internationally recognized theoretical framework established for such assessments. Although domestic studies have surveyed technology attitudes among high school students, university students, and the general public, none have achieved substantial theoretical or practical breakthroughs. To address this gap, this study draws on international standards for technology attitude categorization and develops a questionnaire tailored to China's technological culture across different educational stages (elementary, middle, and high school). The aim is to refine the theoretical framework of technology attitude, enhance measurement tools (questionnaires), comprehensively reflect the current state of public technology attitudes in China, and provide data support for long-term planning of technology education development and national policy formulation.

Keywords: primary and secondary schools; universities; adolescents; attitudes towards technology; technology education

1. Questionnaire design and implementation

1.1 Questionnaire design

The questionnaire consists of two main components: demographic information and technical attitude assessment. The demographic section includes three key aspects: 1) Personal details such as age, gender, and place of birth; 2) Family background including parents 'occupations, household income, parents' technical attitudes, and cultural capital; 3) Educational context covering teaching methodologies, curriculum selection, and activity arrangements. This comprehensive data will serve as

the foundation for subsequent correlation analysis and comparative studies.

The study designed six questionnaires with varying difficulty levels across six educational stages (elementary, middle, and high school). During the development process, researchers were divided into six teams based on their respective stage responsibilities. Each team created three valid test items for each of the three dimensions while maintaining appropriate difficulty levels for each stage, which were then compiled into the second section of the questionnaire. To ensure scientific rigor and professional validity, the Delphi method was employed. This methodology involves experts reaching consensus on specific indicators through face-to-face-free communication, primarily based on the concentration and dispersion of expert opinions.

1.2 Sampling test

This study selected Jiangsu Province as a pilot region, conducting random sampling surveys on students 'attitudes toward technology at schools, including 1 primary school, 1 middle school, 2 high schools, 1 secondary vocational school, and 1 higher vocational college. Questionnaires were distributed through in-person testing and mail delivery. School administrators collected questionnaires from designated institutions or mailed them to school supervisors for distribution and return. A total of 971 questionnaires were distributed, with 924 valid responses collected. Subsequent data analysis was performed using SPSS20.0 statistical software to assess validity and reliability. For items failing to meet validation standards, more appropriate alternatives were selected from the question bank. When issues stemmed from students' attitudes toward answering questions, survey format modifications were implemented to enhance validity. After revisions, the questionnaire underwent Delphi method validation, with final drafts refined based on expert feedback.

1.3 Questionnaire distribution and return

Building upon a questionnaire validated for reliability and validity, this study conducted a nationwide survey on technological literacy among 12,447 students across 92 schools in 18 provinces and municipalities. The sample included 18 primary schools, 16 secondary schools, 18 high schools, 12 vocational schools, 12 higher vocational colleges, and 16 undergraduate institutions, with 11,480 valid responses collected. Over 30 survey coordinators distributed questionnaires to 2-3 schools each, traveling nationwide over two weeks to collect responses. Remote areas utilized mail-in methods, where school administrators collected completed questionnaires via postal delivery.

1.4 Statistical analysis

This study recruited over 100 participants to complete valid questionnaires, with responses systematically recorded using standardized forms. Following data entry, statistical software SPSS 20.0, AMOS 21.0, and Mplus7.0 were employed to conduct validity testing and correlation analysis on the valid survey data. The study calculated percentages for each item across four primary dimensions, seventeen secondary dimensions, and forty tertiary dimensions, along with average scores and standard deviations for each five-point scale. Through data analysis, the relationships between various influencing factors and students' technological literacy were interpreted, their underlying causes elucidated, and constructive solutions proposed based on these findings.

2. Questionnaire reliability and validity analysis

2.1 Reliability analysis

Reliability refers to the stability and consistency of measurement results obtained through a test's scale instrument. The higher the reliability of a scale, the smaller its standard error of measurement. Generally, the reliability coefficient of a total scale should ideally exceed 0.8, while a range between 0.7-0.8 is also acceptable. For component scales, the reliability coefficient should preferably be above 0.7, with 0.6-0.7 being an acceptable range and 0.5 representing the minimum threshold. The reliability coefficients for each dimension in China's technical attitude survey questionnaires for primary, secondary, and higher education students are as follows:

phase of studying	Number of questions	Reliability (Cronbach'sα)
primary school	19	0.864
junior middle school	24	0.876
senior middle school	19	0.886
Secondary vocational education	21	0.862
higher vocational education	22	0.841
undergraduate course	29	0.855

In conclusion, this study adopted the Cronbach's α coefficient as the reliability indicator for each factor in the K-12 technology literacy questionnaire. The reliability results showed that the reliability of technology attitudes among K-12 students was around 0.7, indicating an optimal level that allows for further analysis.

2.2 Validity analysis

The validity measurement of the primary and secondary school students' technological literacy questionnaire can be assessed through content validity. Content validity, also known as logical validity, refers to the appropriateness or representativeness of test items within a measurement instrument. The common method for determining content validity involves experts evaluating the alignment between test items and their intended scope. Throughout all stages from questionnaire development to pilot testing and formal administration, this study engaged numerous experts in the field of technological education and frontline teachers to conduct repeated discussions and revisions on questionnaire items, ensuring that measurement items correspond to their intended content. Additionally, to ensure clear item meanings and age-appropriate language, adjustments were made based on student feedback from the pilot test questionnaire, thereby guaranteeing the content validity of the questionnaire.

3. Subjects of the study

3.1 Trial testing

Prior to the formal assessment, a pilot survey was conducted through random sampling of eight schools in Nanjing. The sample included: 219 students from Xiaozhuang College Affiliated Primary School; 200 students from Mufu Mountain Junior High School affiliated with Nanjing No.29 Middle School; 100 students each from Nanjing No.5 Senior High School and Nanjing No.27 Senior High School; 182 vocational students from Nanjing Commercial School; 180 vocational students from Nanjing Transportation Vocational Technical College; 120 students each from Nanjing University of Science

and Technology Taizhou College of Science and Technology and Nantong Institute of Technology; with a total of 1,221 pilot questionnaires distributed. Of these, 1,191 were returned, achieving a 97.54% response rate. Ultimately, 1,144 valid data points were obtained, representing a 96.05% validity rate. The basic sample characteristics are as follows:

Table 1-15 Basic information of test samples

Phase of studying	School	Number of samples	Percentage
primary school	Nanjing Xiaozhuang College Affiliated Primary School	219	17.93%
junior middle school	Mufu Mountain Junior Middle School, Nanjing No.29 Middle School	200	16.38%
senior middle school	Nanjing Fifth Senior High School	100	8.19%
	Nanjing No.27 Senior High School	100	8.19%
Secondary vocational education	Nanjing Commercial School (Secondary vocational)	182	14.91%
higher vocational education	Nanjing Vocational and Technical College of Communications (Higher vocational)	180	14.74%
undergraduate course	Taizhou Institute of Science and Technology, Nanjing University of Science and Technology	120	9.82%
	Nantong Institute of Technology	120	9.82%

3.2 Formal testing phase

This survey employed random stratified sampling to conduct field tests in urban, rural, private, and vocational schools across 18 provinces, municipalities, and autonomous regions including Jiangsu, Hebei, Chongqing, and Hubei. The study aimed to investigate the current status of technological literacy among students nationwide. A total of 92 schools were selected, comprising 18 primary schools, 16 junior high schools, 18 senior high schools, 12 secondary vocational schools, 12 higher vocational colleges, and 16 undergraduate institutions. Considering factors such as limited comprehension abilities among first, second, and third-grade elementary students, as well as academic pressure on ninth and tenth-year junior high and senior high students, survey participants were specifically selected from fourth, fifth, and sixth grades of elementary schools; first and second grades of junior high schools; and first and second grades of senior high schools.

There are 2,170 primary school students, 1,736 junior high school students, 2,080 senior high school students, 1,989 secondary vocational students, 2,628 higher vocational students and 2,326 undergraduate students, totaling 12,929 students.

Table 1 Basic information of the sample of formal test

Phase of studying	Sex	Frequency	Effective percentage	Hiatus	Amount

primary school	male	1099	50.93%	12	2170
	female	1059	49.07%		
junior middle school	male	862	49.86%	80	1736
	female	794	50.14%		
senior middle school	male	1062	51.11%	2	2080
	female	1016	48.89%		
Secondary vocational education	male	1117	56.76%	21	1989
	female	851	43.24%		
higher vocational education	male	1089	41.74%	19	2628
	female	1520	58.26%		
undergraduate course	male	1050	45.20%	3	2326
	female	1276	54.80%		
			Total	276	12929

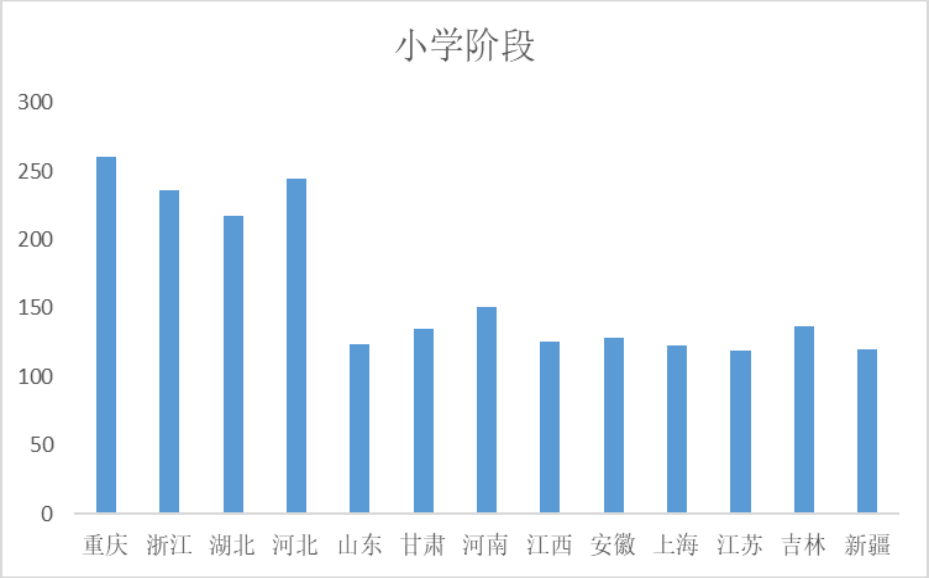

Figure 1 Distribution of primary school population by region

As shown in Figure 1-5, the surveyed primary schools are concentrated in northwest, North and East China. Chongqing, Zhejiang, Hubei and Hebei provinces have the most questionnaires with 260,236,217 and 244 respectively.

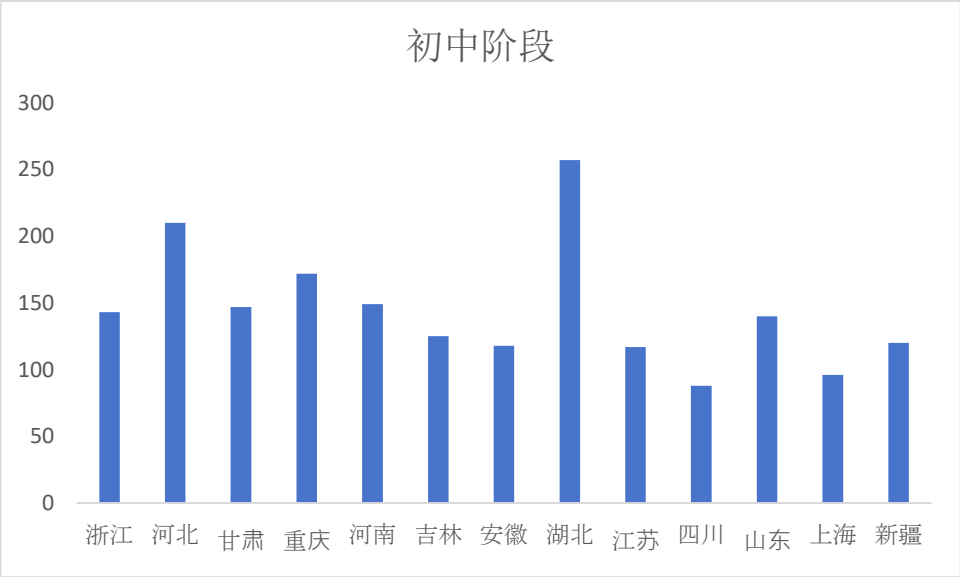

Figure 2 Population distribution by region in junior middle school

As shown in Figure 1-6, the surveyed schools in junior middle school are concentrated in southwest, northwest and east China. Among them, Hubei, Chongqing, Henan and Gansu provinces have the most questionnaires, with 257,172,149 and 147 respectively.

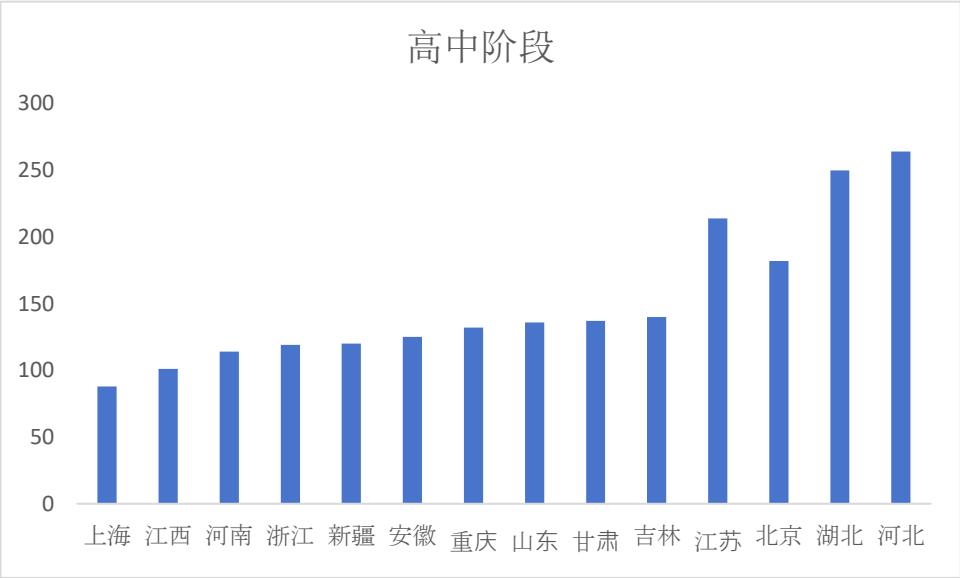

Figure 3 Distribution of population by region in high school

As shown in Figure 1-7, the surveyed high schools are concentrated in northwest and east China. Among them, Hebei, Hubei, Beijing and Jiangsu provinces have the most questionnaires, with 264,250,182 and 151 respectively.

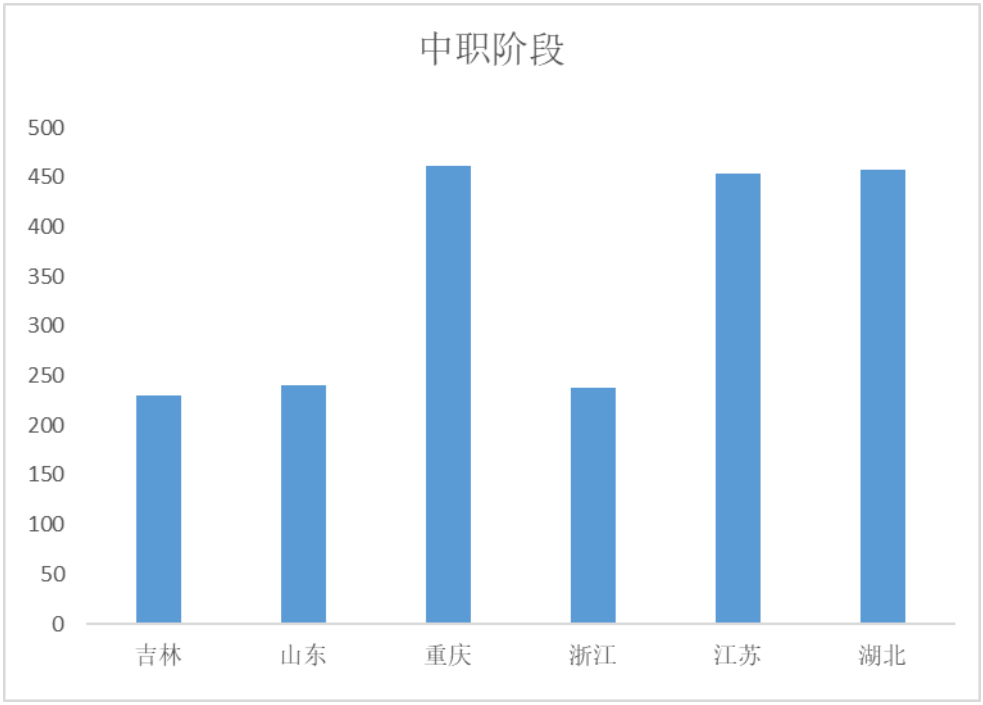

Figure 4 Distribution of population in secondary vocational schools by region

As shown in Figure 1-8, the surveyed schools in secondary vocational stage are concentrated in east China's coastal areas, among which Chongqing, Hubei, Jiangsu and Shandong provinces have the most questionnaires, with 462,457,454 and 240 respectively.

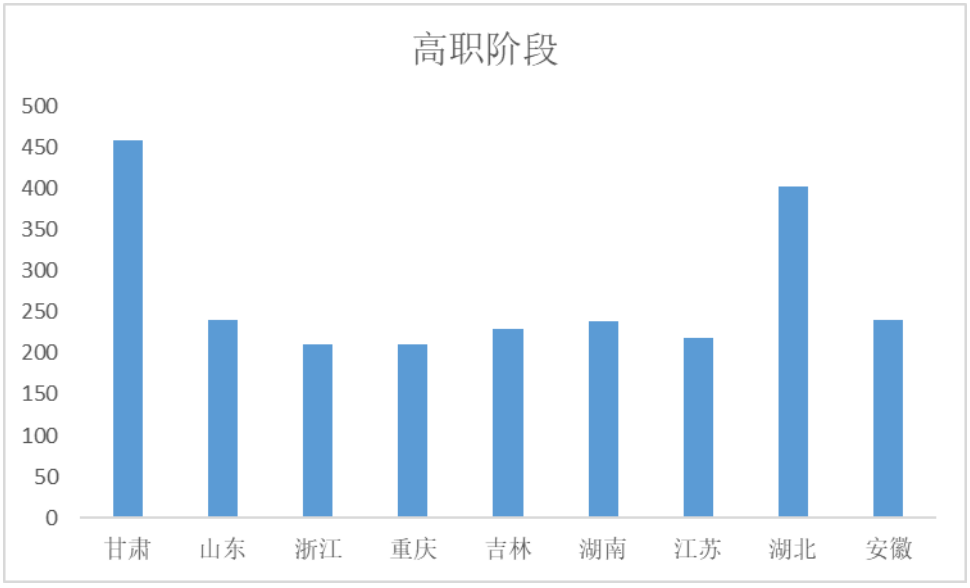

Figure 5 Distribution of population by region in higher vocational stage

As shown in Figure 1-9, the surveyed schools at the higher vocational stage are concentrated in east and central China, among which Gansu, Hubei, Shandong and Anhui provinces have the most questionnaires, with 459,402,240 and 240 respectively.

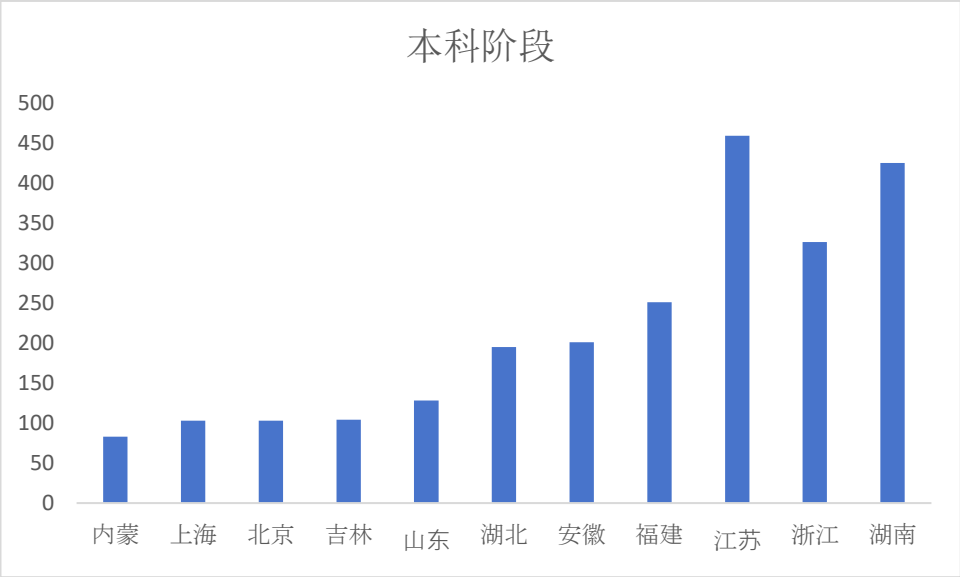

Figure 6 Distribution of undergraduate students by region

As shown in Figure 1-10, the schools surveyed at the undergraduate level are concentrated in north and central China, among which Gansu, Hunan, Hubei and Zhejiang provinces have the most questionnaires distributed, with 459,425,402 and 326 respectively.

4. Current status of technical attitude of adolescents in primary, secondary and tertiary schools

This study measures students 'technological affect through two approaches. First, we employ the "I often take the initiative to participate in..." questionnaire. Responses are categorized using a five-point Likert scale (1-5) with coded values: 5 for strongly agree, 4 for somewhat agree, etc. Statistical analysis of these responses provides data-driven evidence of students' willingness to proactively apply learning technologies. Second, we investigate specific technological affect manifestations through scenario-based assessment items. Each item's mean value is calculated as (frequency 1 * score 1 + frequency 2 * score 2 + frequency 3 * score 3 + frequency 4 * score 4 + frequency 5 * score 5) / total frequency.

4.1 Technical problem handling

4.1.1 More than 70% of primary school students are willing to take the initiative to deal with technical problems

When surveying elementary school students, we used three questions: "If you bought a new toy online and needed to set up its functions after receiving it, how would you handle it?" "If your house mop breaks down, what would you do?" and "If your home fan malfunctions and Mom hires a technician to fix it, what would you do during the repair process?" The table below shows that over 70% of students in all three scenarios expressed willingness to actively engage with technology, with average scores exceeding 4 points. Notably, toys closely related to their daily lives particularly motivated children to explore these devices proactively.

Table 2 Attitude of primary school students to deal with technical problems

	Effective sample	Mean	Effective percentage				
			Never willing	Under protest	Not necessarily willing	Willing to compare	Willing to do that
The Toy Question	2113	4.46	2.51%	2.98%	9.56%	16.00%	68.95%
Mop	2120	4.08	4.48%	5.66%	16.60%	23.92%	49.34%
Electric fan question	2114	4.05	3.78%	4.78%	18.54%	28.67%	44.23%

Note: The mobile phone usage options are as follows: Willing to explore and use—read the product manual in detail and set up according to its instructions; Reluctant to explore and use—set up based on existing experience; Not necessarily willing to explore and use—try it yourself first, but consult others if it feels too complex; Unwilling to explore and use—ask someone else for help directly; Absolutely unwilling to explore and use—set aside the device.

The options for cleaning mop disposal are as follows: Willing to handle it themselves—search online solutions and attempt DIY repairs; Relatively willing to handle it themselves—repurpose old mops as toys; Not entirely willing to handle it themselves—experiment with repair methods but leave repairs to parents if unsuccessful; Unwilling to handle it themselves—ask parents to fix it; Absolutely unwilling to handle it themselves—discard old mops and buy new ones.

The fan maintenance options are as follows: Willing to participate actively—enthusiastically assisting technicians; Relatively willing to participate—observing and thinking while asking questions; Not necessarily willing to participate—silently observing repair methods; Unwilling to participate—quickly looking away and resuming tasks; Completely unwilling to participate—showing no interest in repairs and continuing with personal activities.

4.1.2 More than 60% of junior high school students are willing to take the initiative to deal with technical problems

We conducted a study using three multiple-choice questions to assess students' technological emotions in specific scenarios: "Your new phone needs activation and setup – how would you handle it?" "If your mop breaks at home, what would you do?" and "When your fan malfunctions and Mom calls a technician for repairs, what steps would you take during the process?" After analyzing the responses, we obtained the following data: The average scores for these questions were 4.48,4.00, and 3.84 respectively. Over 50% of junior high school students demonstrated willingness to participate and explore, indicating their eagerness to engage in hands-on technological activities. This suggests that more than half of these students are proactive in trying to fix their devices or tools themselves, showing

a strong affinity for technology through active participation in technical processes.

Table 3 Junior high school students' attitude towards technical problem handling

	Effective sample	Mean	Effective percentage				
			Never willing	Under protest	Uncertain	Willing to compare	Willing to do that
Mobile phone questions	1586	4.48	1.07%	2.27%	11.03%	18.92%	66.71%
Mop	1588	4.00	5.54%	4.16%	23.05%	19.52%	47.73%
Electric fan question	1587	3.84	3.58%	9.39%	23.13%	26.91%	36.99%

Note: The mobile phone usage options are as follows: Very willing to explore and use---can't wait to read the product manual carefully and follow its instructions for activation and setup; Relatively willing to explore and use---will try activating and setting up based on existing experience; Not necessarily willing to explore and use---will attempt it independently first, but will seek help if it feels too complicated; Unwilling to explore and use---will directly ask others for assistance; Absolutely unwilling to explore and use---will set it aside.

The options for cleaning mop disposal are as follows: Willing to handle it themselves—search online for solutions and attempt DIY repairs; Relatively willing to handle it themselves—repurpose old mops as toys through recycling; Not entirely willing to handle it themselves—experiment with repairs but leave repairs to parents if unsuccessful; Unwilling to handle it themselves—let parents assist with repairs; Absolutely unwilling to handle it themselves—discard old mops and buy new ones.

The fan maintenance options are as follows: Willing to participate actively—enthusiastically assisting technicians; Relatively willing to participate—observing and thinking while asking questions; Not necessarily willing to participate—silently observing repair methods; Unwilling to participate—quickly looking away and resuming tasks; Completely unwilling to participate—remaining uninterested in repairs and continuing with personal activities.

4.1.3 More than half of high school students are willing to take initiative to deal with technical problems

We conducted a study using three multiple-choice questions to assess students' technological

emotions in specific scenarios: "Your new phone needs activation and setup – how would you handle it?" "If your mop breaks at home, what would you do?" and "When your fan malfunctions and Mom calls a technician to fix it, how would you assist during repairs?" After analyzing the responses, we obtained the following data: The average scores for these questions were 4.42,3.65, and 3.64 respectively. Over 50% of high school students expressed willing participation and strong willingness to participate, indicating that more than half of junior high students actively attempt hands-on solutions for mobile phone maintenance and tool usage. This demonstrates their proactive engagement in technological processes and a natural affinity toward technology.

Table 4 Attitude of high school students to deal with technical problems

	Effective sample	Mean	Effective percentage				
			Never willing	Under protest	Uncertain	Willing to compare	Willing to do that
Mobile phone questions	1984	4.42	0.45%	1.81%	13.05%	27.67%	56.96%
Mop	1985	3.65	8.77%	7.81%	30.28%	18.24%	34.81%
Electric fan question	1987	3.64	3.72%	11.42%	28.89%	28.94%	27.03%

Note: The mobile phone usage options are as follows: Willing to explore usage—read the product manual in detail and activate settings under its guidance; Relatively willing to explore usage—follow existing experience to activate settings; Not necessarily willing to explore usage—try it yourself first, but consult others if too complex; Unwilling to explore usage—directly ask for help; Absolutely unwilling to explore usage—set aside.

The options for cleaning mop disposal are as follows: Willing to handle it themselves—search online solutions and attempt DIY repairs; Relatively willing to handle it themselves—recycle old mops by turning them into toys; Not necessarily willing to handle it themselves—experiment with repair methods but leave repairs to parents if unsuccessful; Unwilling to handle it themselves—let parents assist with repairs; Absolutely unwilling to handle it themselves—discard the old mop and buy a new one.

The fan maintenance options are as follows: Willing to participate actively—enthusiastically assisting

technicians; Relatively willing to participate—observing and thinking while asking questions; Not necessarily willing to participate—silently observing repair methods; Unwilling to participate—quickly looking away and resuming tasks; Unwilling to participate—remaining indifferent to maintenance work and continuing with personal activities.

4.1.4 More than 50% of secondary vocational students are willing to take the initiative to deal with technical problems

A survey on vocational high school students' responses to questions like "What would you do if your household appliance breaks down during repair?" and "Would you try assembling a purchased desk yourself?" categorized participants into five groups based on their hands-on willingness. As shown in the table, only half of the students were willing to assist with appliance repairs or work alongside technicians when their home electronics malfunctioned. Notably, over 60% of these students expressed interest in assembling new desks independently. Both repair tasks scored below average (4 points), yet more vocational students demonstrated enthusiasm for desk assembly than appliance maintenance.

Table 5 Technical problem handling attitude of secondary vocational students

	Effective sample	Mean	Effective percentage				
			Never willing	Under protest	Uncertain	Willing to compare	Willing to do that
Maintenance appliances	1920	3.63	2.29%	12.47%	33.09%	32.47%	19.43%
Assembly desk	1918	3.96	1.25%	10.89%	24.28%	17.46%	46.07%

Note: The repair technician scenario includes the following options: 1) Actively assist as a novice technician; 2) Observe and analyze while posing questions to the technician; 3) Quietly observe the technician's repair process; 4) Look briefly and then continue your own tasks; 5) Show disinterest in the repair work and return to your original activities.

The options for assembling the desk are as follows: assemble according to the instructions after carefully reading them; assemble based on previous experience; try assembling by yourself and then ask the buyer for help after failure; consult a professional; request the buyer to assemble it before shipping.

4.1.5 Most vocational students are not willing to take the initiative to deal with technical problems

In our survey of vocational college students, we used three questions: "When household appliances break down, your mother hires a technician. What would you do during the repair process?" "Xiaoming bought a smart aerial drone and now needs to assemble and use it. If you were Xiaoming,

what approach would best suit your situation?" and "If your phone breaks down, how would your parents react?" The table below shows the average scores of these questions as 2.4, 1.91, and 2.71 respectively, indicating relatively low enthusiasm for technical activities and insufficient willingness to participate in technical processes. Among vocational students, 55.82% prefer "carefully reading the manual and following instructions for assembly and use" when dealing with broken phones, while only 26.28% are willing to enthusiastically help family members repair appliances, demonstrating limited participation willingness in household technical activities.

Table 6 Technical problem handling attitude of vocational students

Title	Effective sample	Mean	Effective percentage				
			Never willing	Under protest	Uncertain	Willing to compare	Willing to do that
Electrical appliances	2485	2.4	26.28	32.31	27.57	10.38	3.5
The drone problem	2456	1.91	55.82	14.78	20.24	7.34	1.8
Mobile phone questions	2510	2.71	28.88	16.53	30.16	10.16	14.26

Note: The options for the electrical appliance question are: A) Greet warmly and assist the technician; B) Observe and think while asking questions to the technician; C) Watch silently as the technician fixes the issue; D) Glance once and then go about your business; E) Show no interest in the repair and continue with your own activities.

The options for the drone topic are as follows: A. Read the manual carefully and assemble and use it according to the instructions; B. Assemble and use it yourself based on previous assembly experience; C. Ask someone else for help after failing to assemble and use it yourself; D. Ask someone directly for advice on how to assemble and use it; E. Have someone else assemble it for you and then use it yourself.

The options for the mobile phone question are as follows: A search the Internet for solutions and try to repair it by yourself; B recycle the waste, remove the useful parts of the old phone and reuse them; C try to repair it by yourself, if not, give it to your parents; D ask your parents to help repair it; E throw away the old phone.

4.1.6. The two cost students are willing to take the initiative to deal with technical problems

To assess undergraduate students 'technical empathy in specific scenarios, we conducted a study using the hypothetical question: "If your dorm air conditioner breaks down and technicians come to fix it while you're there, what would you do?" Statistical analysis of student responses revealed the following data: 16.55% actively observed while thinking, 4.17% enthusiastically asked questions when encountering difficulties, and nearly half (40.20%) remained curious observers. The results demonstrated that students typically engaged in observational thinking rather than immediate

intervention.

Table 7 Attitude of undergraduates to deal with technical problems

	Effective sample	Mean	Effective percentage				
			Never willing	Under protest	Uncertain	Willing to compare	Willing to do that
Air conditioning	2215	2.83	9.46%	24.85%	40.20%	16.55%	4.17%

Note: The options for the air conditioning question are as follows: A. Never care about it and do your own thing; B. Occasionally look at it; C. Curious and observe on the side; D. Watch and think, actively ask questions when you don't understand; E. Excited to help.

4.2 Participation in technical activities

4.2.1 More than 60% of primary school students are willing to participate in technology-related activities in real life

As can be seen from the table below, in the following six technical activities in real life, the average value of most primary school students' options is more than 3 and close to 4, which shows that primary school students are very willing to participate in technical activities in real life.

Table 8 Attitudes of primary school students to participate in technical activities

	Effective sample	Mean	Effective percentage				
			Strongly disagree	Not quite agreed	Approve of	In favour of the comparison	Strongly endorse
a	2082	3.56	7.20%	14.60%	27.67%	15.85%	34.68%
b	2068	3.25	13.68%	20.07%	20.74%	18.28%	27.22%
c	2059	3.25	13.36%	17.78%	26.76%	14.33%	27.78%
d	2047	3.34	11.72%	15.88%	27.50%	16.56%	28.33%
e	2047	3.37	12.51%	15.73%	23.79%	18.08%	29.90%
f	2083	3.43	12.77%	13.15%	25.59%	15.07%	33.41%

Note: a I often communicate with my classmates about technical information, b I often spend time to master the operation of a new toy, c I often participate in making competitions, d I will try to repair damaged objects, e I often pay attention to technical content on the Internet, f I often make handwork in my spare time.

4.2.2 More than 60% of junior high school students are willing to participate in technology-related activities in real life

Statistical analysis of junior high school students' preferences reveals the following results: In daily life,

the average scores for frequently exchanging information with peers (3.63), regularly assembling items independently (3.28), participating in technology-related competitions (3.30), attempting to repair broken objects (3.55), following technology-related content (3.53), and engaging in extracurricular craft projects (3.35) are all above average. These figures demonstrate that over 60% of junior high school students show strong enthusiasm for participating in technological activities in their daily lives.

Table 9 Attitude of junior high school students to participate in technical activities

	Effective sample	Mean	Effective percentage				
			Strongly disagree	Not quite agreed	Approve of	In favour of the comparison	Strongly endorse
a	1645	3.63	4.13%	13.19%	32.46%	16.23%	33.98%
b	1622	3.28	7.58%	24.97%	24.41%	17.57%	25.46%
c	1613	3.30	9.61%	17.98%	31.18%	15.44%	25.79%
d	1614	3.55	5.70%	13.14%	31.23%	20.20%	29.74%
e	1612	3.53	6.76%	14.14%	29.28%	18.49%	31.33%
f	1624	3.35	9.85%	18.66%	26.97%	16.26%	28.26%

Note: a I often communicate with my classmates about technical information, b I often spend time to master the operation of a new toy, c I often participate in making competitions, d I will try to repair damaged objects, e I often pay attention to technical content on the Internet, f I often make handwork in my spare time.

4.2.3 Less than half of high school students expressed "somewhat agree" or "strongly agree" on the following technical activities

After statistical analysis of students' options, the results are shown in the following table. In real life, the average value of "I will try to repair damaged objects" is 3.39, while that of "frequently participating in making competitions" is 2.62, and other technical activities are basically "approved".

Table 10 Attitude of high school students to participate in technical activities

	Effective sample	Mean	Effective percentage				
			Strongly disagree	Not quite agreed	Approve of	In favour of the comparison	Strongly endorse
a	1971	3.14	6.90%	26.13%	31.35%	17.35%	18.26%
b	1966	3.22	7.68%	24.06%	27.62%	20.19%	20.40%

c	1962	2.62	19.72%	32.82%	24.87%	10.70%	11.88%
d	1959	3.39	6.53%	15.16%	33.74%	22.05%	22.51%
e	1965	3.20	8.40%	21.58%	31.30%	19.49%	19.24%
f	1961	3.07	11.37%	24.68%	29.12%	15.76%	19.07%

Note: a I often communicate with my classmates about technical information, b I often spend time to master the operation of a new toy, c I often participate in making competitions, d I will try to repair damaged objects, e I often pay attention to technical content on the Internet, f I often make handwork in my spare time.

4.2.4 More than 70% of secondary vocational students are willing to take the initiative to participate in technical activities related to life

As shown in the table below, among six real-life technical activities, vocational high school students most frequently engage in three: regularly exchanging technical information with others, organizing and managing items independently, and attempting to repair broken objects. The average scores for these three activities are 3.69,3.58, and 3.48 respectively. The activity with the lowest participation willingness is regularly participating in technical competitions, which has an average score of 3.29. Overall, vocational high school students demonstrate a strong willingness to participate in technical activities, with approximately 80% showing active engagement in such activities.

Table 11 Attitude of secondary vocational students to participate in technical activities

	Effective sample	Mean	Effective percentage				
			Strongly disagree	Not quite agreed	approve of	In favour of the comparison	strongly endorse
a	1896	3.69	4.80%	11.70%	28.36%	20.35%	34.58%
b	1882	3.58	4.67%	12.53%	31.70%	22.46%	28.41%
c	1882	3.29	9.03%	19.49%	31.44%	15.24%	24.59%
d	1878	3.48	5.75%	13.79%	34.35%	17.78%	28.17%
e	1872	3.42	6.73%	16.29%	31.62%	18.43%	26.76%
f	1891	3.43	8.30%	14.96%	31.34%	16.44%	28.75%

Note: a I often communicate with my classmates about technical information, b I often spend time to master the operation of a new toy, c I often participate in making competitions, d I will try to repair damaged objects, e I often pay attention to technical content on the Internet, f I often make handwork in my spare time.

4.2.5 The emotional attitude of vocational students in active learning and application of technology in real life is generally between disapproval and approval

As can be seen from the table below, in the following six technical activities in real life, the average

value of most vocational students' options is more than 2 and close to 3, which shows that vocational students are not willing to participate in technical activities in real life.

Table 12 Attitude of vocational students to participate in technical activities

	Effective sample	Mean	Effective percentage				
			Strongly disagree	Not quite agreed	Approve of	In favour of the comparison	Strongly endorse
a	2512	2.51	23.93%	22.25%	34.79%	16.72%	2.27%
b	2507	2.68	18.19%	22.74%	35.34%	20.46%	3.23%
c	2489	2.89	16.83%	18.2%	31.3%	26.88%	6.75%
d	2492	2.59	20.47%	21.99%	39.33%	14.89%	3.29%
e	2491	2.74	18.63%	19.51%	35.85%	21.52%	4.46%
f	2509	2.76	17.74%	19.21%	37.23%	21.00%	4.70%

Note: a I often communicate with my classmates about technical information, b I often spend time to master the operation of a new toy, c I often participate in making competitions, d I will try to repair damaged objects, e I often pay attention to technical content on the Internet, f I often make handwork in my spare time.

4.2.6 Undergraduate students have strong technical interest and motivation when facing new technologies

This paper examines the technical attitude of undergraduate students, including technical interest and technical motivation in technical emotion. The results show that

When new technologies (such as semiconductor technology) are introduced, undergraduate students demonstrate significant interest in technological development. Their average scores for key questions are: "What are the risks of developing this technology?" (3.16), "What are the risks of not developing it?" (3.08), "Who will adopt this technology?" (3.31), "Who will control this technology?" (3.29), "Who will benefit or suffer from this technology?" (3.51), and "What impact will this technology have on my life?" (3.84). These figures indicate that over half of students exhibit strong technological interest and motivation when encountering new technologies.

Table 12 Attitudes of undergraduates to participate in technical activities

	Effective sample	Mean	Effective percentage				
			Will not	Rarely	General Assembly	Get together	Frequently
a	2146	3.16	7.74%	15.74%	29.75%	32.67%	7.52%

b	2177	3.08	5.72%	21.97%	32.72%	27.69%	5.50%
c	2163	3.31	4.17%	14.36%	30.44%	36.46%	7.57%
d	2172	3.29	4.90%	17.02%	27.21%	34.14%	10.10%
e	2172	3.51	3.65%	12.21%	24.51%	38.35%	14.66%
f	2174	3.84	2.84%	6.41%	19.73%	37.49%	27.00%

Note: When a new technology (like chip technology) is introduced, do you consider these questions? a What are the risks of developing this technology? b What are the risks of not developing it? c Who will adopt it? d Who will control it? e Who will benefit or suffer from it? f How will this technology affect my life?

5. Conclusions and recommendations

5.1 Conclusions

5.1.1 There is a gap between students' technical attitude and the social demand for technology

In this transformative era of technological advancement, humanity has gained unprecedented convenience in production and daily life, with technology becoming increasingly indispensable. While technological development depends on human factors, social structures, political systems, and economic conditions, it also exerts reciprocal influences. When properly managed, technology can drive positive outcomes; when mishandled, it may lead to negative consequences. To thrive in this digital age, students must develop technical literacy through understanding, applying, and evaluating technologies to inform decision-making and form independent perspectives. Moreover, mastering essential technical competencies is crucial for both professional success and everyday living. Research findings reveal that while students across educational levels demonstrate positive attitudes toward technology, they still face challenges including superficial understanding, inadequate knowledge acquisition, and limited practical skills – gaps that highlight the disconnect between current technological demands and existing educational capabilities. This reality underscores the urgent need for education systems to evolve in tandem with our rapidly changing technological landscape.

5.2.2 There is a gap between students' technical literacy and the educational goal of comprehensive development of human beings

A student with strong technological literacy is undoubtedly someone who possesses ideals, practical skills, design capabilities, and creative abilities. The integration of knowledge and action, along with physical and mental harmony, serves as the primary indicators of technological literacy. However, sampling survey results reveal that while students demonstrate relatively strong information technology knowledge and skills, their comprehensive technical competencies—encompassing hands-on abilities, practical application, design proficiency, and problem-solving capabilities—are less than ideal across broader technological domains. The four dimensions of technological literacy—knowledge, skills, thinking patterns, and attitudes—interact and reinforce each other, collectively forming a complete and systematic framework. These four dimensions require coordinated development; any imbalance in their progress will directly impact the overall advancement of technological literacy.

5.2 Recommendations

5.2.1 Pay attention to the unique value of technical education for the development of students in primary and secondary schools, and enhance the status of technical education

Technology permeates our surroundings, profoundly shaping how we learn, live, work, and even think – an influence we can not ignore. The humanistic dimension embedded in technology transforms technical education into a dynamic learning journey, fostering students 'harmonious development of truth, goodness, and beauty while enhancing their practical skills and cultivating individuality. Technical activities embody aesthetic value and labor education significance through processes like design, creation, and communication, nurturing students' ability to appreciate beauty, innovate aesthetically, and develop a craftsman's spirit of excellence. Emphasizing practice and innovation, technical education cultivates students' observational skills, critical thinking, hands-on abilities, and creative problem-solving through real-world challenges. This approach serves as a vital pathway to improve comprehensive competencies, develop technical literacy, and strengthen national technological competitiveness.

5.2.2 Families, schools and society work together to promote technical literacy education and build a harmonious environment for technical education

School education, family education, and social education form the three pillars of modern education systems, each playing an indispensable role. To advance technological literacy education and cultivate a harmonious environment for technical learning, we must establish a tripartite educational framework that integrates school instruction, community engagement, and family involvement.

The survey findings reveal that students 'technological literacy is closely linked to multiple family factors and the availability of social resources, particularly in today's era where technology has become deeply integrated into family and social life. Current challenges include families over-relying on schools while lacking sufficient societal engagement. To address this, we should strengthen collaboration among these three stakeholders through initiatives like parent-school workshops, family-oriented workshops, and community practice programs. This will help establish a technology education ecosystem characterized by coordinated educational philosophies and complementary resources, ultimately forming a comprehensive cultivation framework that "begins at home, develops in schools, and concludes in society".

5.2.3 Strengthen the construction of an integrated technical education system to ensure effective connection between different educational stages

The current challenges in China's technical education system primarily include: 1) Inadequate comprehensive planning and effective curriculum integration across academic stages; 2) Lack of

progressive progression in teaching objectives; 3) Repetitive and fragmented content that fails to align with students' cognitive development; 4) Outdated teaching methodologies and insufficient emphasis on hands-on, real-world application of technical knowledge.

Therefore, establishing a technical education curriculum system with coherent content and unified educational philosophy holds significant value. First, it strengthens institutional rigidity by incorporating technical education into compulsory courses, aligning with educational reforms, college entrance examination reforms, and student comprehensive quality evaluation systems. Second, it improves standardization frameworks through research and formulation of benchmarks for base construction, team development, staffing allocation, and financial support. Third, it promotes integrated professional technical education curricula, using students' developmental needs as the core logic to establish a curriculum system that defines learning content, progression levels, and teaching methodologies across academic stages. This approach breaks away from traditional content allocation methods that prioritize projects over developmental needs, thereby advancing talent cultivation model reforms. The system ensures vertical integration from primary, junior high, and senior high school education to higher education, while fostering horizontal communication between general education, vocational education, school-based instruction, family education, and social education, encouraging schools to proactively explore innovative talent development models.

5.2.4 Create a good atmosphere for technical education and create a high-quality environment for the development of technical education

The advancement of technical education fundamentally depends on the support of a supportive technological environment, while its value in turn drives social development. These two aspects form an inseparable symbiosis. To strengthen this dynamic, it is imperative to enhance the promotion and development of technological culture, establish accessible and safe venues for hands-on technical experiences, cultivate ethical values regarding technology, foster a positive educational atmosphere, and create an optimal social environment.

(1)Strengthen the construction and publicity of technical culture

The survey revealed that most students have limited memory of domestic technological events and associated figures, with insufficient attention to technology. This situation is largely attributed to inadequate technology promotion efforts. Even when such initiatives exist, they remain confined to specific demographics and domains rather than being integrated into daily life, failing to cultivate a distinct technological culture. Therefore, strengthening technological culture development and promotion at the societal level to foster a positive technological atmosphere is an effective and necessary approach for advancing technology education. For instance, by utilizing street market billboards and digital screens to highlight individuals who have made outstanding contributions to technological endeavors or significant events, students can constantly perceive the value of technology. This approach not only ignites their passion for learning technology but also drives the development of technology education.

(2)Provide convenient and safe venues for technical practice activities

The survey reveals that participation in technical practice activities remains alarmingly low across all educational stages. The primary obstacle stems from the scarcity of accessible venues for such

activities in society, with existing facilities seeing only minimal user engagement. Students consequently fail to experience technology firsthand or consolidate technical knowledge and skills through practical application, which significantly hampers the advancement of technological education. Relevant organizations should establish safe and development-oriented venues tailored to students 'technological learning needs, thereby creating a robust educational resource system that ensures students' authentic engagement with technological applications.

(3)Establish correct technical value ethics orientation

In this era of rapid technological advancement, while innovation thrives, it has also given rise to technological proliferation. This proliferation has introduced misguided trends that misdirect both technological development and education. The negative consequences of these technologies highlight the critical need to establish proper ethical standards for technology in our tech-driven age. As a vital participant in education, society bears responsibilities comparable to those within academic institutions. Rather than merely providing technical guidance, society should primarily serve as a moral compass. To address this, establishing ethical boundaries for technology usage and strengthening regulatory oversight of its legitimacy are essential measures to steer society toward mainstream technological ethics.

5.2.5 Accelerate the construction of a team of full-time and part-time professional teachers for technical education

The construction of majors, the development of courses and the implementation of professional teaching ultimately depend on people. The number of technical teachers directly determines the development trend of technical courses, and the status of teachers 'technical literacy directly affects the teaching quality of technical courses and the development of students' technical literacy.

(1) Increase the number of technical teachers and optimize the structure of technical teachers

China's technical education sector urgently requires more visionary professionals to strengthen its academic framework. We must expand the ranks of technical educators while optimizing their structure, actively recruit talents with multidisciplinary backgrounds in pedagogy, technology studies, and engineering, and foster interdisciplinary collaboration across age groups, professional fields, and career levels. By establishing a faculty system that combines full-time and part-time instructors with well-structured tiers and complementary functions, we can comprehensively enhance the quality of technical education and students' technical competencies.

(2) Solve the problem of technical teacher training through multiple approaches

China can draw lessons from international models of technical teacher training and pursue a comprehensive, multi-channel approach to cultivating technical educators. A diversified training system should be established by offering specialized technical education programs in teacher training colleges, engineering universities, and comprehensive institutions. By integrating educational, scientific, and engineering disciplines through cross-departmental collaboration, we can enhance core faculty development through professional development workshops and global academic exchanges. This integrated strategy will comprehensively elevate technical teachers' professional expertise and instructional capabilities, ultimately building a high-caliber, specialized teaching workforce.

5.2.6 Look at technical practice from multiple perspectives and strengthen the integration of technology with education and life

For primary, middle and university students, technical practice is not only the application of technical knowledge and principles in the actual operation process, but also the integration of technical consciousness, technical thinking and technical attitude in real life.

(1). "Hardware + software" to increase the integration of technology and education

Guided by Marx's theory of technological practice, we should deepen the integration of hardware and software to enhance technology's dynamic and practical applications in education. Schools should proactively incorporate STEM concepts into curricula, increasing student engagement through hands-on equipment operation and project-based learning. This approach fosters achievement and technical literacy through integrated physical and cognitive practices, ultimately achieving comprehensive advancement in technological education from facility development to substantive pedagogical content.

(2) "Demonstration + practice" to deepen the practicality of technical knowledge

When teaching new technologies to primary and secondary school students, educators should emphasize the crucial role of "demonstration + practice". Through hands-on demonstrations by teachers, mentors, or parents, students can better understand the interaction between science and technology through repeated practice. This approach facilitates the transformation of knowledge into practical skills, allowing them to deepen their grasp of technical principles through real-world application and enhance their ability to innovate in practical technology implementation.

(3) "Physical + mental" to strengthen the consciousness of technical practice

The survey reveals that students at all educational levels—elementary, middle, and high school—participate infrequently in technical practice activities, with limited activity diversity. Overall, student engagement in technical activities remains inadequate, with some even never participating in any such activities across different stages. Schools, families, and communities should prioritize providing more "hands-on + mental" technical practice opportunities. By encouraging students to apply their hands-on skills in real-world scenarios, we can enhance their awareness of technology application and practical abilities, ultimately achieving the integration of knowledge and action while fostering a two-way transformation of creativity.

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Classroom culture for dialogue and creativity

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Abstract

This paper investigates the role of dialogue in the secondary school design and technology classroom. It considers the classroom culture factors that can foster or hinder the goals of dialogic education for secondary school children (11-18 year-olds). The research in oracy and dialogue education is well established, but is yet to be realised and embedded in education policy in England. Politicians who hold conservative and traditional views on education have suggested that encouraging oracy may lead to 'idle chatter'. This paper explores tensions between research and policy through a critical literature review as the methodology. The search terms included design creativity, dialogic education, material dialogue, and classroom culture; thematic analysis was used to identify key concepts, evidence, and trends.

The discussion identifies and critiques key features of dialogue that support pupils in developing their design and technology capability. Theories associated with dialogic education illustrate how the amalgam of what learners and teachers say, their body language, and the artefacts they engage with (tools, materials, technical components), alongside the various knowledges and skill sets they call on, might be significant in developing creative capability through designing.

Recommendations from this study include that further research is needed to establish the classroom culture factors unique to design and technology dialogic education in secondary school curricula and those which are effective in all classrooms.

Key Words Dialogue, Creativity, Culture, Classroom

The paper considers the classroom culture factors that can foster or hinder the goals of dialogic education for secondary school children (11-18 year-olds), particularly the development of creativity in relation to design and technology. The paper will argue that a classroom culture of collaboration, where feedback is constructive and clearly articulated, is key to supporting pupils' design and technology capabilities, and specifically their creative capabilities.

Therefore, there are five parts.

Part one presents some of the different views of dialogic education.

Part two describes some of the tensions between research and policy in England.

Part three explores the nature of classroom culture.

Part four discusses the interaction between classroom culture and dialogic teaching.

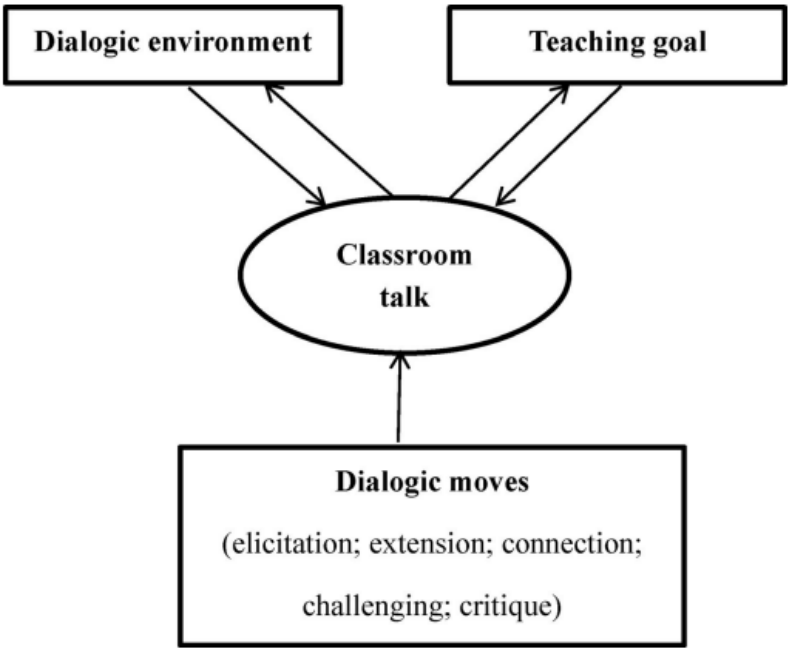
Part five explores how this interaction can be integrated into school design and technology classroom

Dialogic education

There are various approaches to classroom discussion, including dialogic teaching (Alexander, 2020) and collaborative thinking (Mercer and Littleton, 2007). Alexander explored classroom talk in various countries over a ten-year period. He discovered that through dialogue, teachers can engage with children's developing ideas and identify misunderstandings in real time. He then developed, proposed and refined a framework for dialogic teaching that supports children in developing their use of talk to deepen their understanding and foster critical thinking skills. His research focused on whole-class settings where the teacher would lead in organising, encouraging and controlling the dialogue. (Mercer & Littleton, 2007) Also explored the talk in classrooms. However, their focus differed, and they observed small groups of children working together to solve problems; in this context, the teachers served as facilitators of the dialogue rather than active participants in the process. Oracy is defined by Voice 21 as 'articulating ideas, developing understanding and engaging with others through speaking, listening and communication'. Alexander's framework is a pedagogical approach, whereas Mercer and Littleton's is a structured approach that teaches to talk, about talk and through talk. They are both aligned with constructivist theories of learning. Constructivism acknowledges that the starting point from which children learn is not zero, but is built upon their own experiences, thoughts, and beliefs. New knowledge is continually tested against those experiences and can be modified (Driver & Oldham, 1986) as they develop their understanding. In their study, Driver & Oldham (1986) found that some prior knowledge was firmly held by children and remained unchanged despite teaching. Proponents of dialogic education believe that this approach allows children to change their minds more easily than when using more traditional or didactic methods.

The Education Endowment Foundation (EEF) has conducted research which shows clear evidence of the positive impact of dialogic teaching on attainment. The EEF defines dialogic teaching (Jay, 2017) as a strategy aimed at improving pupil engagement and attainment by enhancing the quality of classroom talk. The study was conducted in 38 schools where teachers received training and resources to implement a dialogic teaching intervention. The key findings from this study were that those children who received the dialogic teaching showed increased attainment after the intervention. It was also noted that many school stakeholders witnessed positive effects of the intervention on pupils' engagement and confidence. The teachers involved felt that more than two terms would be necessary to fully embed the approach. In the concluding remarks, it was noted that this was a complex intervention, stating that teachers varied considerably in their assessment of how well a dialogic teaching approach was suitable for specific curriculum subjects. This was linked to the teacher's beliefs in teaching and learning. It was suggested that this would be a helpful focus for further research, which is a gap I aim to address in my study of dialogue in the design and technology classroom.

In a critical review of four frameworks, Cui and Teo (2021) proposed a model with four elements:



They state that the dialogic environment is the first aspect to consider, as although a conducive environment cannot guarantee dialogic talk, it would be impossible without it. They state that classroom cultures take time to establish and acknowledge that negotiation between the teacher and pupils is a vital aspect of this development. The arrows in two directions in the model illustrate the interdependence between the dialogic environment and classroom talk, as well as the teaching goal. If there isn't a clear teaching goal, then the talk may be an enjoyable interaction rather than a purposeful one. Cui and Teo (2021) include dialogic moves in the model, which can be summarised as the type of talk.

This paper will focus on the dialogic environment and the factors that can promote or impede classroom talk. The dialogic environment is also described as a classroom culture, classroom environment or classroom atmosphere. Before discussing classroom culture, it is essential to consider the tensions surrounding dialogic teaching.

Tensions between research and policy in England.

Although there is mounting research evidence regarding the benefits of dialogic teaching (Alexander, 2020; Skidmore & Murakami 2016, 2016; Wegerif, 2019) it has yet to be widely adopted in practice and to date has not been seen in policy in England. Dialogic teaching is a long-term developmental pedagogy that, when successful, can lead to improved reasoning,

engagement, and attainment (Mercer & Littleton, 2007), and is a transferable skill that bridges school subjects and extends into adult life.

High-stakes summative assessment policy in England, where school league tables are published and teachers are incentivised with performance-related pay, presents tensions with any pedagogy where formative assessment is dominant, including dialogic teaching. In an era where prescriptive or formulaic teaching is increasingly evident, a complex pedagogy that involves carefully constructed interactions and responses presents another tension due to the evolving nature of such dialogue.

This has been exacerbated in recent years by a 'knowledge-rich' curriculum, which was introduced as part of the 2014 national curriculum reforms. The Conservative party in government and the Education minister at the time had very traditional views of education and rebuked the idea of including oracy or dialogic teaching in the curriculum, claiming 'it would lead to idle chatter' (Alexander, 2020), which would then impact on pupils' behaviour and teachers' control. The Labour government has been in power since 2024. The now prime minister, Sir Keir Starmer, when in opposition, set out on a mission to break down barriers to opportunity at every stage, in a speech. He said that his government will 'weave oracy through the new national curriculum'. We await the publication of the National Curriculum review, which has been commissioned and is expected to be released in the autumn of 2025.

Classroom culture

Cui and Teo (2021) argue that classroom culture is the foundation of dialogic teaching, as a safe, non-hierarchical space is required for authentic dialogue.

(Bennett, 2020)In his book running the room, which focuses on pupils' behaviour and habits, he defines classroom culture as the beliefs and values of the classroom. What does the group think is important, and what matters to them?. He breaks this down into three parts: social norms, routines, and feedback. Or in other words, make it normal to do the right thing, teach children habits that help them flourish and let them know how they are doing. He states that building a classroom culture is difficult and takes time. "It involves directing the students' appreciation of what is valuable and important towards those things the teacher knows to be useful or good or valuable."

Many aspects of school life and the organisation of a large institution are set, for example, walking on the left when moving around the building. Within classrooms, however, we often see different interpretations of these. Bennett advocates the stance 'my room, my rules', which he admits does not sit well with everyone. Still, he believes that teachers should take responsibility for the curriculum, classroom activities and social behaviour.

A teacher's view and beliefs significantly impact the classroom culture. A traditional teaching model, which emphasises the transmission of knowledge, has different expectations for norms and routines in teaching and learning compared to a classroom where co-construction is valued.

Interaction between classroom culture and dialogic teaching

(Alexander, 2020) describes six principles for dialogic teaching,

- Collective
- Supportive
- Reciprocal
- Deliberative
- Cumulative
- Purposeful

He explains how the first three, collectivity, supportiveness and reciprocity, characterise the classroom culture where dialogue is most likely to succeed. (Mercer & Littleton, 2007) explain how co-creating the ground rules between the teacher and class is at the heart of the thinking together approach, where children use language to think together. In previous work, Mercer categorises classroom talk into three distinct types: disputational, cumulative, and exploratory. Disputational is when children disagree. Cumulative is where children take turns talking and building ideas from one another. Exploratory talk is a process where ideas are shared, critically evaluated, questioned, and built upon to foster a shared understanding. This is the most useful for pupils to think together. (Mercer & Littleton, 2007) argue that effective exploratory talk and thus thinking together can only happen when a safe, supportive, and collaborative environment exists. These are closely linked to the three principles Alexander describes as most likely to enable dialogue to succeed.

In a blog post (Mannion, 2020), the importance of talk ground rules is discussed. He advocates for this and states it is the most impactful practice I have ever implemented as a teacher. He goes on to discuss social and cultural norms, highlighting how some are beneficial and others less so. He provides some examples that may be unhelpful for children in dialogic classrooms, such as: "Don't disagree with your friends – back them up, come what may." He then explains the rationale for children and teachers co-creating ground rules, which give children a sense of ownership.

The following table applies some ground rules that may be agreed upon (Mannion, 2020) and identifies those related to the collective, supportive, and reciprocal aspects, as stated by Alexander (2020). The nature of the class and task will determine which ground rules are appropriate. We can see here that several ground rules are required to cover all three principles. Mannion suggests that around 5 - 7 positively phrased rules be agreed upon.

Ground rules (Mannion, 2020)			
Everyone is encouraged to contribute	collective		
Everyone listens actively	collective	supportive	
People ask questions	collective		reciprocal
People share relevant information			
Ideas and opinions are treated with respect		supportive	
There is an atmosphere of trust		supportive	
There is a sense of shared purpose	collective	supportive	
Contributions build on what has gone before			reciprocal
People give reasons for their thinking			
Ideas may be challenged	collective		
The group seeks agreement for joint decisions	collective		

We now move to consider how the classroom culture for effective dialogic teaching can be embedded in the secondary school design and technology classroom.

Dialogic education and secondary school design and technology classroom

Much of the research on classroom talk has been conducted in primary school classrooms, where the classroom teacher is responsible for the same group of pupils over an academic year for all or most subject areas. This differs from secondary schools, where the norm is for children to have specialist teachers for each subject. The implications of this are that one teacher in one space fosters a common culture across all subjects, which is distinct from that of different secondary school classrooms and teachers. There is also the implication that the time spent in the same primary classroom with the same peer group and teacher may lead to relationships being built and developed that differ from those formed in multiple secondary school classrooms with many different teachers and changing groups of peers.

The EEF study (Jay, 2017), which involved teachers implementing dialogic teaching approaches and then engaging in a reflective interview, reported that teachers varied considerably in their assessment of how well a dialogic teaching approach was suitable for specific subjects; this may also have a larger impact on secondary specialists and their perception of its suitability for them. It was also noted that some of these views may have been preconceived before involvement in the study.

Voice 21 is a charity with the mission to transform the learning and life chances of young people through talk. The charity is affiliated with School 21 in East London, an all-through school that encompasses both primary and secondary phases of education. (Gaunt & Stott, 2019) Both teachers in School 21 and leaders in Voice 21 state that dialogic education does not happen by chance. The expectations of the participants must be explicit. Much like creating ground rules, as described by Mannion, Mercer, and Littleton, they describe it as 'setting up the rules of the game'. Knowing what is expected of them allows pupils time to consider the issue rather than how to play the hand.

They also describe how children must be explicitly taught how to talk and listen within a dialogic task. They suggest assigning children specific roles for the activity, another focus layer for each pupil. For example, the instigator, builder, challenger, clarifier, prober or summariser. These are also methods of scaffolding the activity. Teachers might scaffold a writing task, but they can also provide support structures to novice talkers and remove them when they become more proficient. Another example of scaffolding is a listening ladder (Listening Ladder, 2020). This states a linear list of listening skills pupils can use to plan or assess their listening during a dialogic task.

Rachel Higginson, the founder of Finding My Voice, an organisation which runs projects supporting young people in both primary and secondary phases to physically and metaphorically find their voice, identifies four aspects of authentic oracy: expressing, collaborating, exploring and presenting. She draws on several ideas to achieve these, including self-determination theory (Ryan & Deci, 2017). This theory explains how people are motivated by autonomy, competence and relatedness. They describe autonomy as self-endorsed as opposed to independent. Competence is about mastery, and relatedness is about feeling connected. Feeling connected links to both Alexander's collective and reciprocal approach, as well as Mercer and Littleton's supportive and collaborative environment, which fosters a sense of belonging with others, where you can contribute and learn from one another.

There are four widely accepted pedagogical approaches (McLain, in Hardy, 2023) to teaching design and technology in secondary schools. We will now consider the opportunity for dialogic education for each of the four.

Mainly making is a useful pedagogical approach when specific materials or processes are to be taught. This will typically be a teacher-led task with a set of instructions or procedures for pupils to work through to achieve the same or very similar outcome. For example, a pewter cast keyring. The opportunity for dialogic education here is limited, as the pupils are simply following a 'recipe,' as Rutland describes in Benson & Lawson (2017).

Mainly, designing allows pupils the freedom of design without the constraints of the materials, equipment, or time available for making. The Young Foresight project (Barlex, 2004) provided teachers with a toolkit for designing activities. Key features of this project include that pupils work in groups, design for the future, not themselves or their family members, and present their ideas. Emphasis was placed on three teaching strategies: appropriate questioning, modelling ways of working and connected thinking. Dialogic education is integral to this.

Exploring technology and society is often taught through the use of case studies, product or life cycle analyses. The teacher's choice of structure will determine whether this is an opportunity for dialogic education or not.

Design and making, which remains the most prevalent pedagogy seen in secondary schools, may include dialogic education in the designing phase, but by the making phase, the pupils are focused on their solutions and are constrained by this.

Through empirical classroom research, I aim to determine if this speculation is substantiated.

Summary

This paper began by considering some of the different views on dialogic education. It outlines the evidence for dialogic education and shows that teachers' beliefs are a core feature influencing the curriculum, classroom activities, and social behaviour. The second part of this paper describes some of the tensions between research and policy in England, specifically the reluctance of politicians to encourage talking within classrooms due to concerns that it may promote off-task behaviour and or lead to teachers losing control.

Part three examines the nature of classroom culture, which again underscores the impact of a teacher's views and beliefs. A traditional teaching model, which emphasises the transmission of knowledge, has different expectations for norms and routines in teaching and learning compared to a classroom where co-construction is valued. Part four is a discussion of the interaction between classroom culture and dialogic teaching. Comparing the principles of dialogic teaching with the co-construction of ground rules from thinking together and Mannion, followed by identifying how these can be used to select the appropriate ones for the class and task collectively.

Part five explores how primary classroom talk research can be applied in the secondary classroom. Drawing on research from an all-through school and a project spanning multiple phases. Teachers'

views and beliefs influence classroom culture and the success of dialogic teaching. Having a clear teaching goal (Cui & Teo, 2021), along with explicit instruction and scaffolding (Gaunt & Stott, 2019), can ensure the successful implementation of dialogic education in secondary schools. The implications for design and technology classrooms are that dialogue can support children in talking and learning together to develop their design and technology capabilities. Considering each of the four pedagogical approaches, designing and exploring technology offers the most significant scope for dialogic education. The extent to which a teacher values the pupils' co-construction of knowledge and understanding will underpin the success of dialogic education in design and technology, alongside the scaffolding and rehearsal of such techniques. For example, feedback can support pupils' creative designing. (Schut in Hardy, 2023, p. 238). When provided with feedback, learners may reject or ignore it; the reasons for this may be attributed to the value they place on the feedback received (Bennett, 2020) or their motivation to modify their design. As Driver & Oldham (1986) found, dialogic teaching made it easier for children's firmly held prior knowledge to change. Schut & Blom (2019) discovered, in a study examining convergent and divergent thinking, that design feedback is often ignored or rejected by pupils. They attribute several possible reasons for this: learners' limited experiences or training in convergent thinking, learners' inexperience in dealing with convergent feedback, or the teachers' and clients' limited training in giving appropriate feedback. My research will examine how dialogic education in a supported classroom environment influences children's responses to feedback from peers and teachers, and how this, in turn, affects their creativity when designing.

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