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Pupils' Attitudes Towards Technology Conference

K-12 technology and engineering education and student development

The 41st International Pupils' Attitudes Towards Technology Educational Research Conference

Nanjing Normal University, Nanjing, China

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Welcome

Dear PATT41 delegate,

It is my great pleasure to welcome you to attend the 41st International Pupils' Attitudes Towards Technology Educational Research Conference. This esteemed event is designed to create a platform where top research findings in the field of technology education can be perfectly integrated with perspectives on the future development of technology and engineering education. The symposium will be held at the prestigious Nanjing Normal University, China, from 22nd to 25th October 2024.

Nanjing Normal University (NNU) is a renowned institution with a history of over 120 years. It offers a comprehensive range of disciplines, with education being a particularly strong and multifaceted research area. The university also encompasses engineering fields such as mechanics, electronics, energy, chemistry, automation, and environmental science, leading to extensive interdisciplinary studies. Among these, K-12 technology and engineering education is one of our key areas in addressing global technological changes and pursuing educational ideals. Currently, NNU hosts 981 international students from 133 countries and has established close cooperative relationships with 232 universities worldwide.

Your presence is what makes PATT41 a highly prestigious and impactful event. We are privileged to host esteemed educators, industry experts, academic researchers, and graduate students from across the globe. Your participation is vital in fostering a collaborative environment where innovative ideas are shared, and transformative education strategies are developed. The symposium will provide an excellent opportunity for you to connect with professionals, exchange knowledge, discuss issues, and jointly promote the future development of technology and engineering education for children and adolescents.

The NNU School of Education and Science has been committed to education that inspires technology and engineering education, espousing quality, compatibility, and sustainability. In December 2022, UNESCO Director-General Audrey Azoulay officially approved and signed an agreement to establish the UNESCO Chair on Technology and Engineering Education for Children and Adolescents at Nanjing Normal University, with the renowned education expert Professor Gu Jianjun serving as the chairholder. This marks a new stage in the development of global technology and engineering education for children and adolescents and is a testament to our long-term commitment to achieving equitable and high-quality education. It also provides a solid platform for our extensive exchange and in-depth cooperation.

Welcome to the 41st International Pupils' Attitudes Towards Technology Educational Research Conference. We look forward to sharing an exciting, challenging, and meaningful conference experience with you!

Jianjun Gu (Conference Chair)

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尊敬的第 41 届中小学生技术态度国际学术研讨会（PATT41）参会者：

非常荣幸地欢迎您参加第 41 届中小学生技术态度国际学术研讨会。这是一项备受推崇的盛会，旨在搭建一个平台，使技术教育领域内的顶尖研究成果与对未来技术与工程教育发展方向的展望得以完美融合。本次研讨会将于 2024 年 10 月 22 日至 25 日在享有盛誉的南京师范大学隆重举行。

南京师范大学（NNU）是一所拥有 120 多年悠久历史的名校，学科门类齐全，教育学科具有厚重的特色和多方面的研究优势，同时学校还设有机械、电子、能源、化学、自动化和环境等工科领域，从而产生多方面的交叉学科。其中，K-12 技术与工程教育就是我们应对全球科技变革、追求教育理想的重要领域之一。目前，NNU 拥有来自 133 个国家的 981 名国际学生，并与全球 232 所大学建立了紧密的合作关系。

正因为有了您的参与，PATT41 才成为了一个备受瞩目且影响深远的盛会。我们深感荣幸能够接待来自世界各地的知名教育家、行业专家、学术研究人员及研究生。您的参与对于构建一个共享创新理念、制定变革性教育战略的协同环境至关重要。此次研讨会将为您提供一个与专业人士建立联系的绝佳机会，大家可以在此交流知识、探讨问题，共同推动儿童青少年技术与工程教育的未来发展。

南京师范大学教育科学学院拥有的国家中小学通用技术教材建设重点研究基地团队，一直致力于推动技术与工程教育的创新发展，并倡导教育的质量、兼容性和可持续性。2022 年 12 月，联合国教科文组织总干事奥德蕾•阿祖莱女士正式批准并签署了协议，在南京师范大学设立联合国教科文组织儿童青少年技术与工程教育教席，著名教育专家顾建军教授担任教席主持人。这标志着全球儿童青少年技术与工程教育迈入了新的发展阶段，也是我们为实现公平优质教育而不懈努力的长期承诺的见证。同时，这也为我们的广泛交流和深度合作提供了坚实的平台。

再次热烈欢迎各位参加第 41 届中小学生技术态度国际学术研讨会！我们期待与您共同度过一段激动人心、充满挑战且意义深远的会议时光！

顾建军（会议主席）

会议网址：https://patt41nanjing.com　　会议邮箱：patt41nanjing@126.com

Conference Theme

The main theme for PATT40 is "*K-12 technology and engineering education and student development*", inviting delegates to present original research and scholarship exploring axiological, epistemological, and ontological aspects of the subject. The conference theme and sessions are organised under four strands:

STRAND 1. Promotion the awareness of technology and engineering in K-12 education;
STRAND 2. Characteristics and cultivation of technology and engineering thinking in K-12 education;
STRAND 3. Challenges in K-12 technology and engineering education;
STRAND 4. Pedagogical content knowledge and teaching strategies in K-12 technology and engineering education.

Contents

Conference Papers

A primer on the use of R to analyse think aloud protocols through linkography

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Abstract

Linkography is a data analysis method for studying designers' cognitive processes during design activities. It allows for a detailed examination of designerly thinking, breaking down complex processes into discrete design moves and offers a dual perspective: a microscopic view of moment-to-moment development in design thinking and a macroscopic overview of broader trends and patterns in students' design processes. This paper demonstrates how to analyse think aloud protocols in R, using linkography to reveal the cognitive mechanisms underpinning design thinking and 2) to compare different processes of designing. In this article, we use illustrative examples to demonstrate the methodological principles that underpin the effective use of linkography, thereby deepening the understanding of design cognition. Additionally, the article discusses how these methodological insights can enhance pedagogical strategies, highlighting linkography's role in promoting effective design learning in technology education. This primer aims to inform researchers on the application of linkography and illustrate its significance in refining current and future research and practice in Technology Education.

Key Words: design process, design thinking, linkography, methodology, RStudio

1. INTRODUCTION

Understanding the thinking and acting processes that occur during design activities is crucial to enhance both technology education research and practice. However, capturing and studying these internal and external processes in authentic ways poses significant challenges, often leading researchers to rely on post-hoc methodologies. For instance, portfolios are commonly used to infer design processes; however, these curated collections often reflect a selective and potentially biased view rather than the designerly activity itself. As such, there is a need to explore ways of investigating in-situ designerly activities. To this end, we intend to contribute methodologically to this need in the technology education field by exploring the use and analysis of linkography in RStudio, an open-source environment for the R programming language for analysis and visualisation. There is no package currently available in R to enable linkographic analysis immediately within the software. The end-goal of this work is to develop a free web application using R wherein those interested can conduct, and if then desired transparently report, linkographic analyses without knowledge of the R language. This paper specifically outlines how to perform Linkographic analyses within the R environment and thus showcases the current state of progress in this endevour, which is that code has been written to conduct basic linkographic analyses and present useful outputs. We have not made this code available as it is a work in progress and is not immediately adaptable for diverse applications. The next stage of this project will be to develop generalised code where different datasets can be readily handled. Ultimately, this work will then be refined and used to enable analyses in the future open access web app.

Linkography is a think-aloud protocol analysis method that allows researchers to visually depict and analyse the design processes of individuals or teams in qualitative and quantitative ways (Goldschmidt, 2014; Kan, & Gero, 2017). A linkograph shows how moment-to-moment thoughts and ideas are connected and developed during design processes. Specifically, linkographs trace the sequence of connections between students' thoughts, ultimately leading to the formation of design ideas. In this regard, linkography has emerged as a prominent, process-based analysis method in design disciplines (Goldschmidt, 2014). Through linkography researchers can investigate and characterise patterns of thinking and doing by constructing links between units of cognitive activity, providing valuable insights on the structure and influencing factors of during though instantiation and development (Goldschmidt, 2014; Kan, & Gero, 2017).

The value of linkography has been demonstrated in various professional design contexts to understand how design ideas are conceptualized and developed (Goldschmidt, 1995), exploring differences of designers with art and engineering backgrounds (Zeng et al., 2024), the role of sketching in idea development (van der Lugt, 2005), team communication during design tasks (Jiang & Gero, 2017), and moments of creative discovery (El-Khouly, 2019). More recently, the use of linkography has been applied to educational contexts (Blom & Bogaers, 2020; Jackson, 2018), and seems to be an emerging methodology. However, there are limited guidelines to support researchers in using linkography as a research method, and even fewer which enable a qualitatively transparent process which is important for technology education research (Buckley et al., 2022). To this end, we provide guidance that might support researchers who are interested in examining the design cognition of students.

2. CONSTRUCTING LINKOGRAPHS

When constructing a linkograph, verbal utterances in a think aloud protocol are first segmented into a sequence of "design moves" (or simply "moves"). Visual data can also be included in this segmentation process, for any additional design moves that were instantiated during sketching or 3D modelling activities. These design moves are then analysed to identify the connections, or links, between them (Goldschmidt, 2014). Each link that is identified is a backlink, meaning it connects a current design move to a previously generated one (Goldschmidt, 2014). Once backlinks for a design session are established, forelinks, which indicate the influence of earlier moves on subsequent ones, can be identified retroactively. The distinction between backlinks and forelinks is crucial: backlinks trace the path leading to a move's generation and are determined at the time the move is made, while forelinks can only be established after all backlinks have been identified (Goldschmidt, 2014). Although Goldschmidt (2014) suggests that the link-coding process relies on a 'common sense' approach and domain understanding, Hatcher et al. (2018) proposed guidelines for link-coding. According to these guidelines, links between design moves are made when participants explicitly relate their thoughts or actions to previous ones, through visible hand gestures, sketching, 3D modelling, or writing, or when there are structural, functional, or behavioural similarities, or when moves occur in sequence within the same chain of thought.

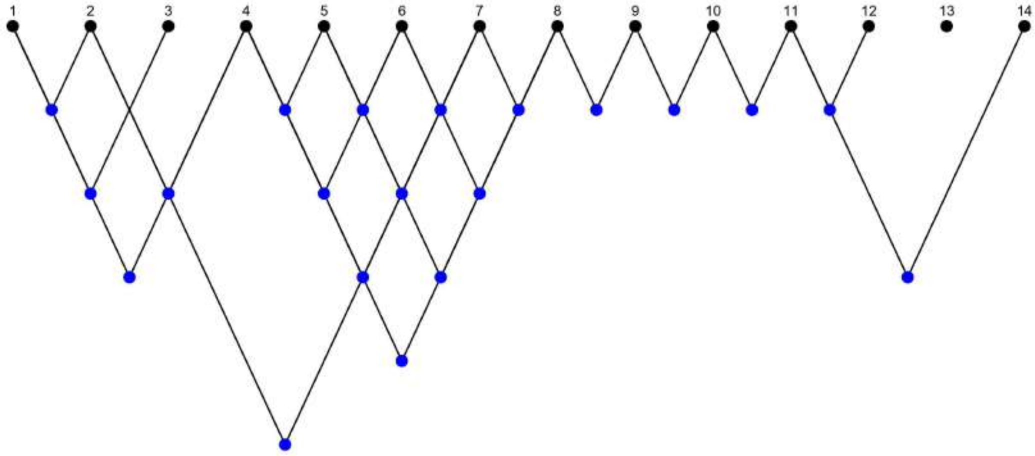
Figure 1 illustrates a hypothetical process of link coding in a Microsoft Excel template. This is the most basic format of data in which links can be presented in, but for further analysis such as the inclusion of archiographs (cf. Blom & Bogaers, 2020) as will be described later in this article, additional data could be included in the dataset. The first column (column A) represents each design move which has been determined through the think aloud protocol analysis, and subsequent columns (columns B to E) represent backlinks. In this example, there were 14 design moves in the dataset, and to take one for explanation, move 4 has backlinks to both moves 1 and 2. This data is hypothetical, and the moves could come from one or multiple designers. Like with archiographs, additional columns in the dataset could be used to specify the designer, and this information could be presented on the linkograph. For now, whether the data come from one or multiple designers is not critical to the functionality being developed.

Figure 1.
Example of a dataset for linkographic analysis.

	A	B	C	D	E
1	move				
2	1				
3	2	1			
4	3	1			
5	4	1	2		
6	5	4			
7	6	5	4		
8	7	6	5	4	2
9	8	5	6	7	4
10	9	8			
11	10	9			
12	11	10			
13	12	11			
14	13				
15	14	11			

Once the links between design moves have been coded as shown in Figure 1, a linkograph can be generated. As part of this project, the initial action was to write R code to read data in this format and generate a linkograph. Figure 2 shows a basic linkograph generated from the data in Figure 1, however an advantage of doing this in R is that is can be edited to provide different insight or supplemented with additional data to support data integration and triangulation.

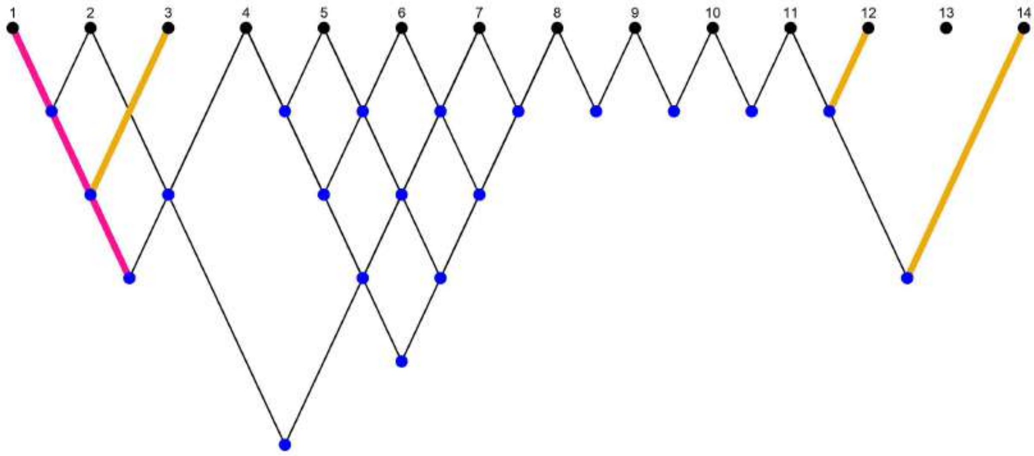
Figure 2.
A basic linkograph constructed in RStudio from the dataset presented in Figure 1. The black dots represent design moves, and the blue dots represent links between design moves.



Five types of design moves are represented in linkographs, with each revealing unique reasoning patterns during a design process. *Orphan moves* are isolated actions or thoughts that demonstrate isolated instances of generation or evaluation. In Figure 2, move 13 is an example of an orphan move. *Unidirectional backlink moves* focus on past activities. In Figure 2, moves 3, 12, and 14 are unidirectional backlink moves as they are only connected with moves which occurred prior to them. *Unidirectional forelink* moves introduce new ideas that may link back later, such as move 1 in Figure 2 which is only connected to subsequent moves. *Bidirectional moves* show moments where both generation and evaluation are demonstrated (moves 2 and 4 to 11 in Figure 2), indicating a designer's or group of designers' effort to maintain continuity while planning ahead. *Critical moves* are rich in links compared to other moves and can be unidirectional or bidirectional, however the criticality is directional. For example, a bidirectional design move may have few backlinks but many forelinks, and could be a critical forelink move. Typically, 10 to 12% of the most interconnected moves are classified as critical (Goldschmidt, 2014). These design moves are indicators for design productivity and are significant due to their high interconnectivity, which leads to synthesis in design (Goldschmidt, 2014). A move with many backlinks shows extensive development of previous ideas, while one with many forelinks represents a pivotal new thought crucial in the overall design process.

As noted, by analysing the data in R, move types can be identified in the data through an examination of link patterns between moves and these can then be highlighted in the linkograph to support analysis. For example, Figure 3 shows a linkograph which highlights both unidirectional forelink and unidirectional backlink moves. This is for demonstration purposes as other move types such as orphan moves, critical moves, and bidirectional moves could also be highlighted, and they could also be presented on the same linkograph or across separate linkographs as deemed useful by the analyst. The choice of colours is also customisable.

Figure 3.
Linkograph with unidirectional forelink moves (pink) and unidirectional backlink moves (orange) highlighted.

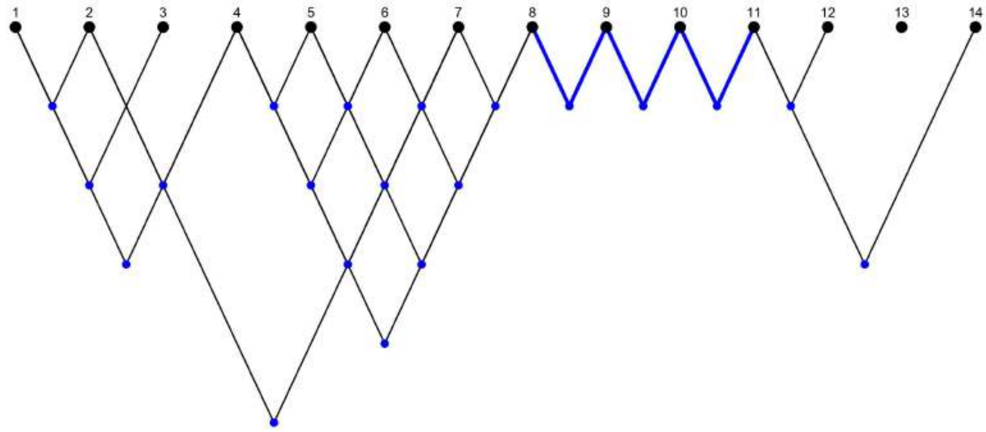


Once the different types of design moves have been identified, several analyses can be useful for researchers. For instance, examining the ratio between critical backlink moves and critical forelink moves can provide insights into how designers balance reflecting and evaluation on ideas with proposals of new ideas. Additionally, analysing the frequency and distribution of orphan moves can reveal insights about the coherence of the design process. Researchers might also look at the distribution, ratio and sequence between different move types to understand the flow and dynamics of the design process.

3. QUALITATIVE CHARACTERISTICS

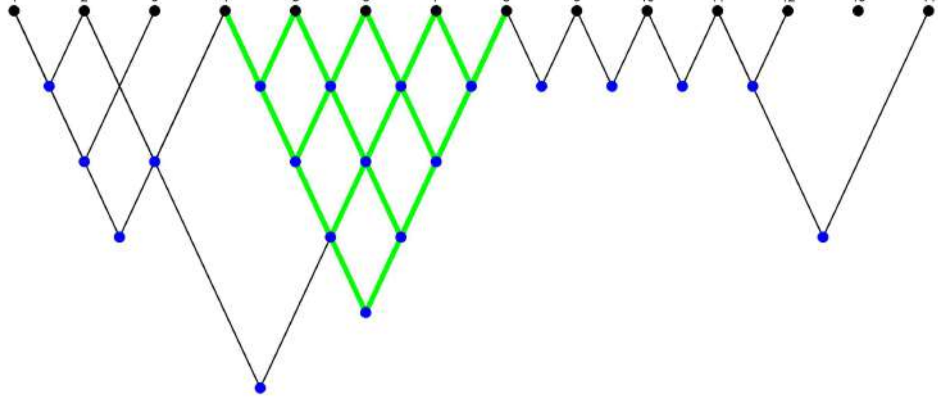
In the qualitative analysis of linkography, three visual link patterns can be inspected to reveal how design ideas emerged during designing (Goldschmidt, 2014). The first of these, sawtooth patterns, represent a linear step-by-step progression where one proposition builds on another, though they may not facilitate deep exploration of the design problem itself (Goldschmidt, 2014). Again, patterns of links between moves can be analysed in datasets in R to enable sawtooth pattern identification. In the current example it is relatively easy to visually identify the sawtooth pattern between moves 8 and 11, but in larger datasets where linkographs are more complex the capacity to automate this process is useful. For this, a function in R has been developed which can identify these sequences and present them on the basic linkograph. The output is shown in Figure 4.

Figure 4.
Linkograph with sawtooth pattern identified (blue) based on automated detection of move connection patterns.



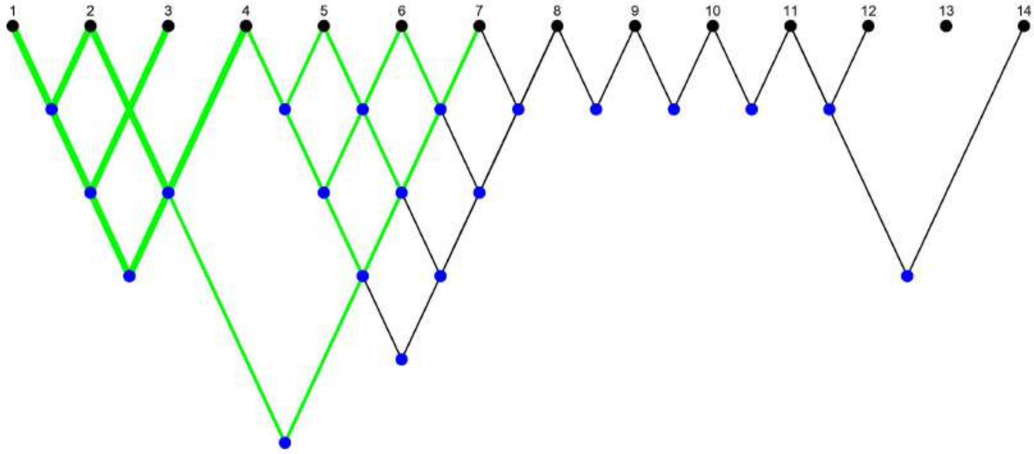
The second and third of these are chunks and webs, which are both series of moves with several links amongst each other. Chunks are blocks of links among successive moves that connect mostly within themselves, showing isolated segments, where ideas are developed within a confined scope (Goldschmidt, 2014). Webs consist of qualitatively fewer moves with many links, indicating areas of intense interactivity, indicating thought clusters that are highly integrated. The determination of both pattern types is qualitative, and similar to other forms of qualitative analysis researcher inference plays a significant role. Not to discount this, but there is a capacity in R to support this process in a transparent and quantifiable way. Specifically, we have developed a function wherein a researcher – or more specifically the linkograph analyst or linkographer – can specify a minimum and maximum number of moves to allow in a sequence, and a minimum and maximum percentage of possible connections which need to be connected amongst these moves, and have these move and associated links displayed. As such, they may specify lower numbers of moves and higher percentages of connections for webs, and higher numbers of moves with lower percentages of connections for chunks. For example, in the basic linkograph shown in Figure 2, there is a clear pattern between moves 4 and 8, where all possible links between these moves are linked. This could be considered as a web. Consequently, in the function we have developed, if the minimum and maximum number of moves in sequence are specified as 3 and 8 respectively, and the minimum and maximum percentage of connected links are both set to 100%, the returned plot (Figure 5) highlights this set of moves and associated links.

Figure 5.
Series of between 3 and 8 moves with 100% of possible links connected.



Alternatively, the parameters can be adjusted. If, by way of example, the minimum and maximum number of moves are still specified as 3 and 8 respectively, but the percentage of connections is set to between 50% and 90%, the returned plot (Figure 6) presents two different sequences of moves. The pattern between moves 2 and 7 has 8 of 15 potential links (53.34%) which could be considered as a chunk.

Figure 6.
Series of between 3 and 8 moves with 50% to 90% of possible links connected. Line weight is used to distinguish discrete patterns.



This functionality is not intended to subvert the qualitative nature of this process, but rather to support the analyst in their identification of webs and chunks for further enquiry. Linkographers can also interpret their own moves and chunks manually. By using a hypothetical dataset with a low number of moves as we do in this article this function may not seem as immediately useful, however in more typical linkographs which could have closer to 100 or more moves, being able to identify move patterns or moments in the design activity which could be worth investigating further can have significant utility value. The hypothetical parameters used here were for demonstration purposes and have no inherent meaning beyond illustrating that if this functionality were to be used to identify webs and chunks it can be done so in a reproducible manner. Understanding chunks, webs, and sawtooth patterns in linkography can reveal pedagogically relevant actions. By recognizing these patterns as they happen during designing, teachers can use questioning and scaffolding to encourage interactivity and idea synthesis to ultimately enhance the overall quality of design thinking.

4. QUANTITATIVE CHARACTERISTICS

Conducting linkography also allows researchers to quantitatively analyse data from the verbal protocol, including metrics such as the link index and link span. The link index, which is the ratio of links to moves, provides insights into the overall connectivity and complexity of the design process. As such, in a study where several linkographs are being used to describe the design process of different people, the link index can be used as a comparison measure. In the example dataset being used in this article the link index is

$$\frac{Total number of design moves}{Total number of links} = \frac{14}{20} = 0.7$$

The link span measures the temporal distance between linked moves, indicating how ideas are revisited or evolve over time. This can also be determined in R by identifying connected moves and the distance between them. The result can be presented as a matrix-style table, which can be outputted in .html format such that it is suitable for a web app, as shown in Figure 7. These metrics, combined with the identification of different design moves, or other variables coded in the verbal protocols allows researchers to discover intricacies involved in design thinking.

Figure 7.
Link span table.

Move	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	1													
3	2													
4	3	2												
5				1										
6				2	1									
7		5		3	2	1								
8				4	3	2	1							
9								1						
10									1					
11										1				
12											1			
13														
14											3			

5. INCORPORATING THE USE OF BI-COLOURED ARCHIOGRAPHS

As previously noted, additional data can be integrated with linkographs to support further insight being gained. In addition to linkographs, the use of bi-coloured archiographs (cf. Blom and Bogaers, 2020) can enhance the analysis of design processes by visually demonstrating relationships between different design moves. Bi-coloured archiographs use distinct colours to represent backlinks and forelinks. Such archiographs could illustrate, for example, the designer who made each move to see between-designer relationships, characteristics of moves such as whether they involved internal thinking or external modelling, or any other categorical feature associated with design moves. Archiographs added to linkographs therefore allow researchers to easily differentiate between connections that reflect past influences and those that indicate forward-thinking or new idea generation. By incorporating bi-coloured archiographs, researchers can gain a clearer and more nuanced view of the design process, facilitating a deeper analysis of the cognitive strategies and decision-making patterns involved in creative work. This additional layer of visualisation helps to visualise the flow of thought, providing valuable insights for improving design education and practice.

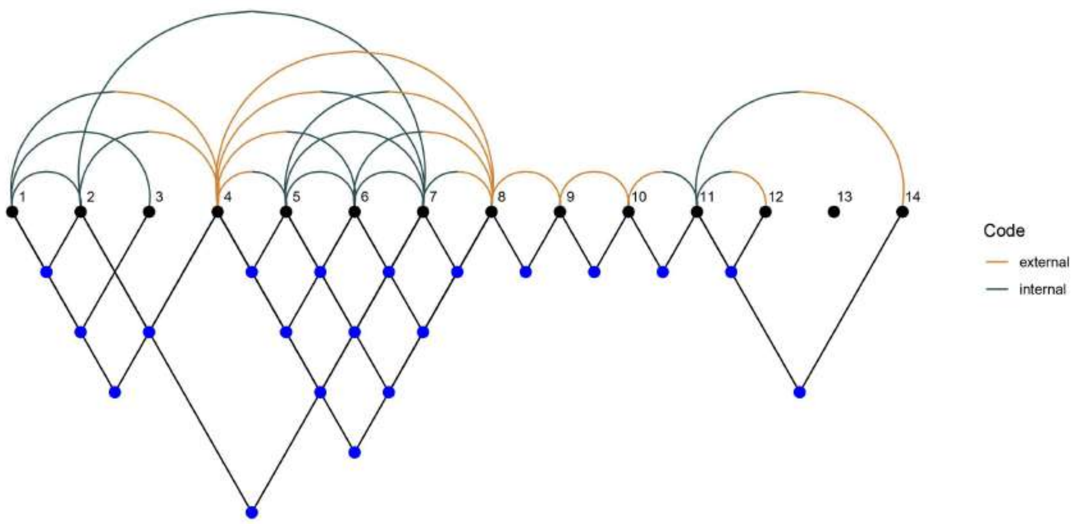
To achieve this in R, an additional column needs to be added to the dataset in which each move is coded according to the analysts needs. An example of this using the codes “internal” and “external” for demonstration purposes is illustrated in Figure 8. If desired, this same method could be used to clarify different designers to highlight interactions between people.

Figure 8.
Example of a dataset for linkographic analysis with additional codes for supplementary archiograph.

	A	B	C	D	E	F
1	move	code				
2	1	internal				
3	2	internal	1			
4	3	internal	1			
5	4	external	1	2		
6	5	internal	4			
7	6	internal	5	4		
8	7	internal	6	5	4	2
9	8	external	5	6	7	4
10	9	external	8			
11	10	external	9			
12	11	internal	10			
13	12	external	11			
14	13	internal				
15	14	external	11			

The "code" column in Figure 8 can be treated in a similar way to the "move" column which was used to create the linkograph based on the unnamed link columns. However, rather than being below the horizontal axis where moves are labelled, they are presented above it. Further, they are presented as discrete colours based on the applied categorical code. For example, in Figure 8 it is clear that move 2 is coded "internal" which is presented by grey arcs in Figure 9, move 4 is coded "external" which is represented by orange arcs in Figure 9, and moves 5, 6, and 7 are coded again as "internal". Viewing these in Figure 9, in isolation of the other linked moves for explanatory purposes, makes it clear the external move 2 connected into an internal move 4, which in turn connected forward to external moves 5 to 7. Being aware of the colour coding enables the reading of archiographs more easily than the dataset such that consequential moves and patterns can be identified for further qualitative analysis.

Figure 9.
Linkograph with added archiograph.



6. DISCUSSION AND CONCLUSION

In this paper we provide description for researchers to use linkography to analyse design processes, and showcase our current progress on developing a set of analytical tools to support this within the R environment, offering both qualitative and quantitative insights into students' design reasoning. By examining different types of design moves and their interconnections, researchers can gain a detailed understanding of moment-to-moment development in design thinking, as well as broader trends and patterns. The introduction of bi-coloured archiographs further enhances this analysis by clearly distinguishing between past and future-oriented connections, enriching our comprehension of the design process. These methodological advancements not only deepen our understanding of design cognition but also have significant pedagogical implications. They enable educators to tailor their teaching strategies to support various phases of the design process, ultimately fostering more effective and creative design learning. This primer serves as a valuable resource for researchers and educators in technology education, guiding them in the application of linkography to refine current and future research and practice.

7. REFERENCES

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Simulating adaptive comparative judgement sessions to determine the effect of judge disagreement on reliability

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Abstract

The use of adaptive comparative judgement (ACJ) for the assessment of creative works in technology education has grown in popularity in the last decade. In brief, ACJ involves a cohort of assessors making holistic judgements on a collection of work. Specifically, two pieces of work are presented for comparison and the assessor selects the "better" of the two based on either a personal construct of capability or on some pre-defined criterion. This process of pairwise comparison making is repeated and governed by an adaptive algorithm, and the results of several pairwise comparisons are analysed to produce a rank order of the included pieces of work.

The use of ACJ mitigates limitations in traditional criterion-based assessment related to rubrics including low inter-rater reliability and that rubrics often do not represent the totality of ways in which capability can be demonstrated in responses to open-ended activities. The benefits of ACJ are well documented, but there are also several open questions which need qualification prior to large-scale repeated use. One such question relates to the feasibility of ACJ in terms of the amount of time the process takes. The time required for an ACJ session is a function of the number of judgements required and the time required by assessors to make a judgement. This paper will present the results of a series of simulations conducted to determine, under different judge behavioural conditions (variations in the amount and type of judge disagreement) and with different stopping rules (80% and 90% reliability), the number of judgements required for an ACJ session. It is envisioned that the results of this will guide subsequent work on real-world judge decision making to support the determination of ACJ feasibility in comparison to traditional criterion referenced assessment with rubrics.

Key Words: Adaptive comparative judgement, reliability, decision making, simulation.

1. INTRODUCTION

Adaptive comparative judgement (ACJ) is seeing an increase in use in technology education contexts (Bartholomew & Jones, 2022; Bartholomew & Yoshikawa-Ruesch, 2018). The typical argument for its use is that is offers a more reliable method than the use of rubrics for the assessment of student work which is developed in response to an open-ended activity (Kimbell, 2022). In technology education this is often, but not always, contextualised around design activity. Assessment mechanisms are often evaluated based on a series of measurement properties, such as validity, reliability, and feasibility (Bartholomew & Yoshikawa-Ruesch, 2018). Validity in this sense relates to the question "Does the assessment measure what it was intended to measure?" (Jonsson & Svingby, 2007). Reliability relates to consistency, or variability, within the assessment. Variability of assessors can be inconsistency within individual assessors known as intra-rater reliability or between several assessors which is known as inter-rater reliability (Black, 1997). Finally, feasibility concerns the capacity for the assessment mechanism to be implemented in context. If ACJ is going to see widespread adoption (cf. Buckley & Canty, 2022; Seery et al., 2022), those responsible for deciding which assessment mechanisms to use will need to understand how feasible it is, which is a question that is easier to answer with single assessors and moderators implementing rubrics. In this paper, ACJ will be examined through the lens of feasibility and its relationship with reliability. Specifically, the number of comparisons which need to be made to reach a desired level of reliability will be simulated under different behavioural conditions. To contextualise this, the next section will offer a brief account of the method of ACJ, highlighting where reliability and feasibility are relevant factors.

1.1. Reliability and feasibility of adaptive comparative judgement

ACJ presents an alternative method of assessment to criterion reference rubrics. Based on the law of comparative judgement (Thurstone, 1927), ACJ involves a group of assessors making a series of binary comparisons on pairs of pieces of work, and the results of these comparisons are used to generate a ranking of all pieces of work included in the assessment (Hartell & Buckley, 2021; Pollitt, 2012). To begin, a selection of pieces of work, henceforth known as portfolios, are selected for assessment. The determination of what portfolios to include would depend on the purpose of the assessment, but given the argued purpose of ACJ the portfolios would typically be outputs from an open-ended activity. While ACJ could technically be conducted by a single assessor, this would effectively equate to a single person organising the portfolios into a rank from "best" to "worst". The value of ACJ involves creating a single rank from the decisions of multiple assessors, and therefore a group of assessors – as opposed to a single assessor – is also decided upon to complete the ACJ session. The validity of ACJ is often described as inherently related to this decision (Buckley, Canty, et al., 2022; Buckley, Seery, et al., 2022; van Daal et al., 2019). If a cohort of assessors is assembled who do not have the expertise to reasonably evaluate the work, then the resulting ranking of work is unlikely to be reasonably evaluated.

Once the portfolios and assessors are organised, assessors are shown a series of pairs of portfolios and make a binary decision of which they view as “better” or which “wins” the comparison. The portfolios are often digital but can be physical artefacts, so being shown portfolios for comparison often involves a judge seeing two digitised portfolio on a computer but can involve examining two physical portfolios placed side by side, and then a decision is made as to which wins the comparison. This decision is seen as the fundamental reason for high reliability in ACJ assessment, as to make this type of decision is easier to do consistently than ascribing scores against several criteria (Gill & Bramley, 2013; Thurstone, 1927). What “better” and “win” refer to is tied to the purpose of the assessment, but as examples the decisions could be based on which portfolio shows overall more capability, or which shows more evidence of learning. Comparisons are organised into rounds, such that in a single round all included portfolios are paired together. For example, if there were 40 portfolios, a round would consist of 20 comparisons where each portfolio is paired with one other portfolio. Then, if there were 10 rounds in the entire ACJ session, there would be 200 comparisons in the session. More comparisons have been observed to result in a more reliable rank (Verhavert et al., 2019), such that some people have imposed a threshold minimum level of reliability as a stopping rule for determining the total number of comparisons to make (Verhavert et al., 2022), as opposed to stopped after a certain amount of comparisons were made and seeing the level of reliability achieved at the end. As increasing reliability is related to increasing the number of comparisons made, the feasibility of ACJ is directly linked to this. More comparisons equate to more of a time investment, and if the process of ACJ is excessively long then it can become unfeasible in real-world educational settings.

The question then becomes how many judgements are needed in total for a single ACJ session, and how long does it take for each judgement to be made. If this is known, then the feasibility of ACJ can be commented on with the additional consideration of how many assessors are involved. In ACJ, there are two phases which relate to the selection of portfolios to present to assessors for comparison. First there is a “rough sort” phase, and then there is an “adaptive” phase (Pollitt, 2012). A different algorithm is used in each phase to select which portfolios to pair together, and within each phase there are different algorithms to choose from. In the rough sort phase portfolios could, for example, be paired entirely randomly or they could be paired by a “Swiss tournament” approach (Kimbell et al., 2009). An entirely random process would mean that in each round, the portfolios are paired randomly without any consideration being given to previous pairings. In a Swiss tournament, portfolios are paired randomly, but against portfolios with a similar number of wins/losses as themselves. For example, if two rounds of comparisons had been completed, some portfolios would have two wins, some would have have one, and some would not have yet won. For the third round, portfolios with two wins would be randomly paired with others within those that also had two wins. In the adaptive phase portfolios are paired based on how much information the comparison will provide for computing the overall rank. As a simplified example, after a number of comparisons have been made, comparing what is considered the “best” portfolio with the “worst” portfolio would likely not provide as much information as a comparison between two portfolios that were more similar in perceived performance. There are different ways to make information-based decisions such as greedy algorithms (the most informative pair is selected one at a time) or exact algorithms (a series of pairs, e.g., a round, are generated to optimise the amount of information gained from that collection of comparisons). The purpose of using adaptive algorithms is to reduce the total number of comparisons to be made by including more informative comparisons and reducing the number of low information comparisons.

The total number of comparisons needed for an ACJ session is often described as the number of comparisons per representation, where the term representation is a generalised term for portfolio. The number of rounds in an ACJ session equates to the number of comparisons per representation as in each round each portfolio is subject to a single comparison (Verhavert et al., 2019). Taking the example again of having 40 portfolios, after 10 rounds there will have been a total of 200 comparisons with 10 comparisons per representation. Through a meta-analysis of 49 comparative judgement (CJ) sessions, Verhavert et al. (2019) found that for expert and peer judgements, between 10 and 14 rounds are needed to achieve a reliability (scale separation reliability: SSR) of SSR = .70, and between 26 and 37 rounds are needed to achieve a reliability of SSR = .90. Important to note in this meta-analysis is that the included sessions were not adaptive, i.e., it was CJ rather than ACJ assessment. The comparisons were determined by two criteria, portfolios which were compared the smallest number of times, and which had not yet been paired with each other, but not with an information-based decision algorithm, so achieving high reliability would likely take more comparisons than if an adaptive algorithm were used.

Seery et al. (2019), in an investigation where 128 undergraduate students acted as ACJ assessors for work from four conceptual design activities observed that the average times taken to make a single comparison were 154.24 (SD = 117.19), 191.36 (SD = 111.58), 237.38 (SD = 130.48), and 259.77 (SD = 137.40) seconds respectively. Another study by Bartholomew et al. (2018) involved five expert judgements evaluating undergraduate work using ACJ, and the average time per judgement ranged from 55 seconds to 206 seconds. This is very limited evidence, but the average time across each ACJ session is just over 3 minutes for an individual to make a single judgement. Although from CJ rather than ACJ, taking the findings of Verhavert et al. (2019) as an illustrative example for an ACJ session with 40 portfolios, if the goal was a reliability of SSR = .90 and between 26 and 37 rounds are needed, this equates to 520-740 comparisons. In total this could be estimated to take between 1,560 (26 hours) and 2,220 minutes (37 hours). In contrast, to achieve a reliability of SSR = .70, that same ACJ session would be estimated to take between 10 and 14 hours of total time making comparisons. With that information, this time can be divided by the number of judges to determine feasibility. If it were two judges this process may not be feasible, but if there were 10 judges there would be a much smaller time commitment per judge and then the time investment may be worth it to achieve a high level of reliability. There has not been a similar meta-analysis to the work of Verhavert et al. (2019) for ACJ. In this paper, as there are quite a limited number of ACJ studies which have reported the required data, a simulation study is described to estimate the number of ACJ rounds needed to achieve certain reliability levels, and this can then be used to estimate total judging time needs which can be used to determine feasibility.

2. METHOD

2.1. Approach

For this study, a series of ACJ simulations were conducted using the R programming language. A selection of simulations from a larger simulation study will be presented here. The simulations were conducted where each ACJ session included 40 portfolios and 60 rounds (comparisons per representation) of which the first 6 rounds were the "rough sort", and the following 54 rounds were adaptive rounds. Then, for each behavioural condition 100 ACJ sessions were simulated.

For the rough sort rounds, pairing was completely random. At the beginning of each round every portfolio was randomly paired with one other portfolio. As there were 40 portfolios this resulted in 20 randomly produced pairs. The random pairing of portfolios in subsequent rounds was independent of pairings generated in previous rounds. In other words, it was entirely possible for portfolios to be randomly paired with each other multiple times across these first rounds.

For the adaptive rounds portfolios were paired using a greedy algorithm. The following steps were performed:

(i) Using the results of the pairwise comparisons from the first six random rounds, the Bradley Terry Luce model is fit to derive ability scores by

$$\alpha_i = \frac{\sum_j \frac{w_{ij}\alpha_j}{\alpha_i + \alpha_j}}{\sum_j \frac{w_{ji}}{\alpha_i + \alpha_j}} \#1$$

where *i* and *j* are individual portfolios, w_{ij} is the number of wins portfolio *i* has against portfolio *j*, w_{ji} is the number of wins portfolio *j* has against portfolio *i*, α_i is the ability score estimate of portfolio *i*, and α_j is the ability score estimate of portfolio *j* (Hunter, 2004). Initially, all ability scores are estimated as 1 and then normalised to maximum likelihood estimates. The sirt R package is used to compute the BTL model (Robitzsch, 2021).

(ii) These ability scores are converted to logits by

$$logit(\alpha_i) = ln\left(\frac{\exp(\alpha_i - \max(\alpha))}{\sum_{j=1}^{n} \exp(\alpha_i - max(\alpha))}\right) \#2$$

where α_i is each ability score for set $\alpha = \{\alpha_1, \alpha_2, \ldots, \alpha_n\}$.

(iii) A matrix is then created which pairs each portfolio with all other portfolios, and the Fisher Information statistic (I) is computed for each pair of portfolios (e.g., portfolios i and j) by

$$I_{ij} = P_j(\alpha_i)\left(1 - P_j(\alpha_i)\right) \#3$$

where $P_j(\alpha_i)$ is the probability that portfolio *i* wins in a comparison with portfolio *j*, computed by

$$P_j(\alpha_i) = \frac{\exp\left(\alpha_i - \alpha_j\right)}{1 + \exp\left(\alpha_i - \alpha_j\right)} \#4$$

where α_i is the ability score of portfolio *i* and α_i is the ability score of portfolio *j*.

(iv) The matrix is examined, and the portfolio pair which has the highest Fisher Information statistic (how informative the result of a comparison of that pair will be to improving the rank) is set as the first pair in the adaptive pair round, and these portfolios are removed from the matrix. The matrix is then re-examined for the pair that provides the next highest Fisher Information statistic, which becomes the second pair for the adaptive round. This process repeats until all portfolios are put into pairs, and these pairs define the adaptive round.

2.2. Implementation

The above process was implemented under three types of behavioural condition. In this work, behavioural conditions refer to different ways that judges could agree or disagree with each other, and perceive the quality of portfolios, if this were a real ACJ session with real people as judges and real portfolios. There is currently no data to suggest how groups of judges make decisions in ACJ sessions, so three conditions were examined.

In the first condition, ACJ sessions were modelled under the a "uniform disagreement" assumption. Here the result of a decision was based on the portfolio ID number. Portfolios were numbered 1 to 40, and the portfolio with the lower number would win the comparison. In other words, if portfolio 1 was compared with portfolio 2, portfolio 1 was deemed as the winner. Then, random error was systematically introduced in multiples of 5%. One hundred ACJ sessions were simulated with no error, then another 100 with 5%, 10%, 15%, up to 45%. This error involved, in a random x% of decisions, reversed the outcome from the lower numbered portfolio winning to the higher number. This could be viewed in reality as there being two "groups" of judges making different percentages of judgements with perfect inter-rater reliability within groups but absolute disagreement between groups. The group sizes would equate to the percentage of error, so for the 30% error scenario one group represented 70% of assessors and the other 30%. It could also be viewed as a cohort of judges with a certain percentage of disagreement.

The second condition introduced "logistically distributed disagreement". Here, a "win probability" function was used, which was identical to Equation 4. The probability of one portfolio winning was computed through Equation 4 with the current portfolio ability scores used as inputs, and then the outcome was assigned based on the resulting probability of a certain portfolio winning. For example, if portfolio 10 had a 60% chance of winning against portfolio 15, a win result would be 60% likely to be assigned to portfolio 10 for that decision. This condition was then modelled with 0%, 5%, 10%... 50% random error like in the previous condition, with 100 ACJ sessions simulated for each. The logistically distributed error condition added the real-world scenario that even if assessors have strong views on what denotes quality, there can be more easy and difficult decisions to make when portfolios are closer or further away in absolute quality.

The third condition reported in this paper was to introduce skewness to the portfolios included in terms of absolute quality. In this condition, the outcome of decisions were identical to the previous condition without additional random error, i.e., the win probability function was used. However, the included portfolios were sampled from populations with 0.2, 0.4, 0.6, and 0.8 degrees of skewness. This was to simulate the effect of there being more disproportionate amounts of portfolios either side of the mean in terms of absolute quality. For example, there could be a scenario where there are many perceived excellent portfolios and relatively fewer perceived poor-quality portfolios included in the ACJ session. Again, 100 iterations were simulated for each degree of skewness.

3. RESULTS

3.1. Uniform disagreement

The results for the uniform disagreement simulations are illustrated in Figure 1, and Table 1 provides corresponding data of the number of rounds needed to achieve reliability levels of SSR = 0.8 and 0.9 with 80% probability. For example, Figure 1A shows the results of there being no disagreement in assessors. In this case, 8 rounds in total were needed to reach at least 80% probability of achieving SSR = 0.8. Table 1 correspondingly shows that after 8 rounds, 100% of simulated sessions had met or exceeded SSR = 0.8, whereas at 7 rounds (the previous number of rounds, indicated by ⟵) only 20% of simulated sessions had achieved SSR = 0.8, and at 9 rounds (the next number of rounds, indicated by →) 100% of simulated sessions had achieved SSR = 0.8. If assessors behave like this in reality, it can be seen that there are scenarios where SSR = 0.8 won't be achieved within 60 rounds, and with very high levels of disagreement (45%) there is a possibility it would never be achieved.

Figure 1.
Results of ACJ simulations under various percentages of uniform disagreement. Each plot shows SSR per round (grey lines) and the average SSR per round (blue line) for 100 simulations. The amount of disagreement is described in Table 1.

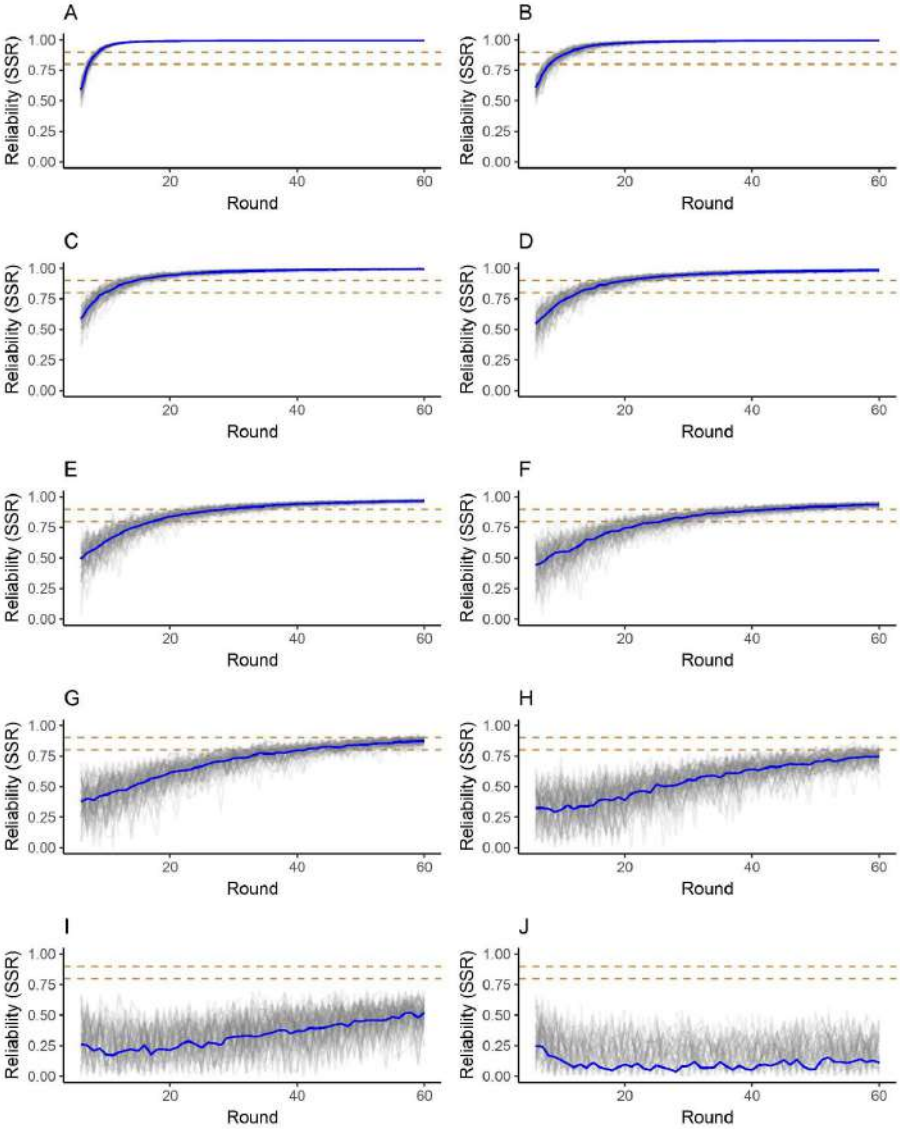


Table 1.
Results of ACJ simulations under various percentages of uniform disagreement.

Percent disagreement	Figure reference	Rounds needed to achieve SSR > 0.8 with 80% probability	Rounds needed to achieve SSR > 0.9 with 80% probability
0	Figure 1A	8 (20% ← 100% → 100%)	9 (0% ← 88% → 100%)
5	Figure 1B	9 (39% ← 84% → 99%)	13 (78% ← 90% → 96%)
10	Figure 1C	12 (76% ← 91% → 97%)	16 (62% ← 85% → 86%)
15	Figure 1D	16 (79% ← 95% → 97%)	22 (64% ← 82% → 84%)
20	Figure 1E	19 (64% ← 80% → 85%)	32 (77% ← 80% → 84%)
25	Figure 1F	90 (73% ← 86% → 90%)	49 (74% ← 85% → 83%)
30	Figure 1G	48 (76% ← 87% → 93%)	- (15% at round 60)
35	Figure 1H	- (14% at round 60)	- (0% at round 60)
40	Figure 1I	- (0% at round 60)	- (0% at round 60)
45	Figure 1J	- (0% at round 60)	- (0% at round 60)

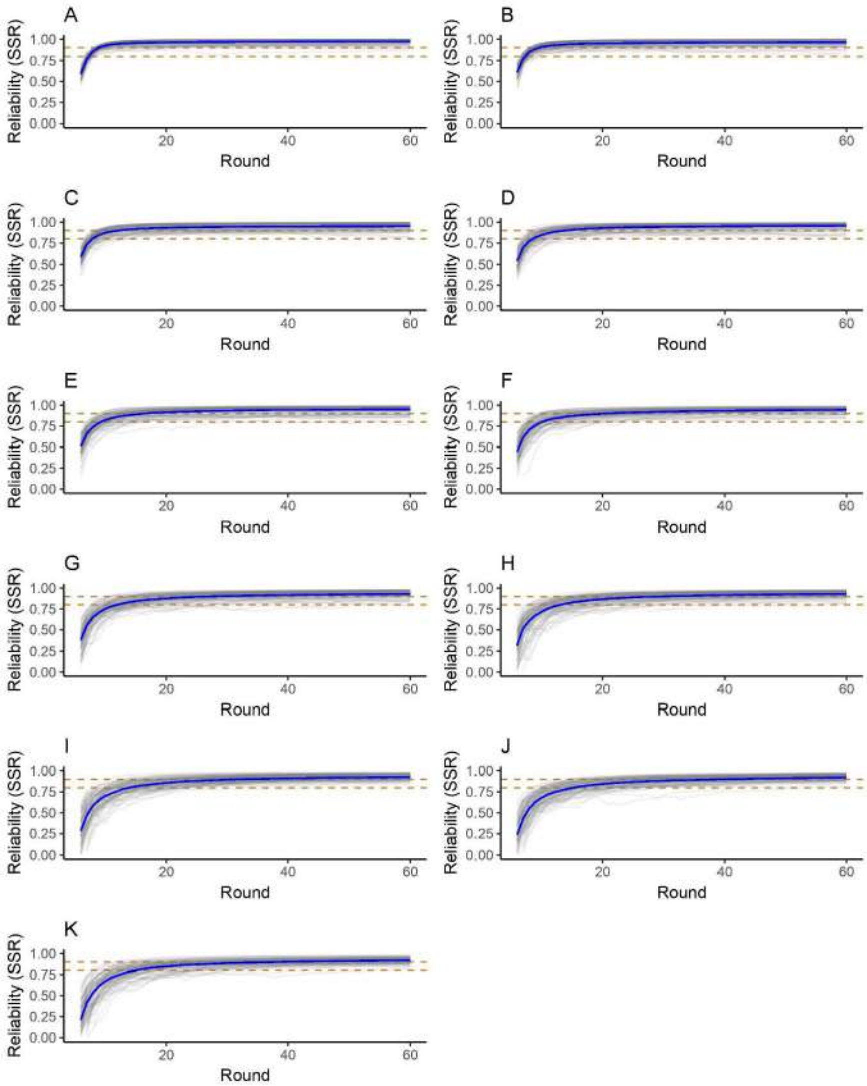
3.2. Logistically distributed disagreement

The results for the logistically distributed disagreement simulations are illustrated in Figure 2, and Table 2 provides corresponding data of the number of rounds needed to achieve reliability levels of SSR = 0.8 and 0.9 with 80% probability. In this condition, there is always at least 80% probability of achieving SSR = 0.8, but to achieve SSR = 0.9 there was just less than 80% probability when 45% and 50% random error was also introduced. Like with the previous condition, with more error included there are more rounds needed to have a higher probability of achieving a higher level of reliability.

Table 2.
Results of ACJ simulations with logistically distributed disagreement under various percentages of uniform disagreement.

Percent disagreement	Figure reference	Rounds needed to achieve SSR > 0.8 with 80% probability	Rounds needed to achieve SSR > 0.9 with 80% probability
0	Figure 2A	8 (24% ← 97% → 100%)	11 (79% ← 85% → 88%)
5	Figure 2B	8 (28% ← 90% → 96%)	14 (79% ← 83% → 85%)
10	Figure 2C	9 (62% ← 81% → 92%)	21 (79% ← 81% → 82%)
15	Figure 2D	10 (62% ← 80% → 88%)	22 (79% ← 80% → 80%)
20	Figure 2E	11 (70% ← 81% → 84%)	32 (79% ← 80% → 80%)
25	Figure 2F	14 (79% ← 87% → 90%)	36 (79% ← 82% → 83%)
30	Figure 2G	16 (79% ← 85% → 85%)	51 (79% ← 80% → 81%)
35	Figure 2H	18 (76% ← 83% → 84%)	54 (79% ← 80% → 82%)
40	Figure 2I	19 (79% ← 80% → 86%)	56 (79% ← 80% → 81%)
45	Figure 2J	21 (79% ← 83% → 87%)	- (77% at round 60)
50	Figure 2K	19 (77% ← 82% → 81%)	- (74% at round 60)

Figure 2.
Results of ACJ simulations under various percentages of uniform disagreement with logistically distributed disagreement. Each plot shows SSR per round (grey lines) and the average SSR per round (blue line) for 100 simulations. The amount of disagreement is described in Table 2.



3.3. Skewed distribution of perceived portfolio capability

The results for the skewed distribution of ability scores of portfolios with logistically distributed disagreement simulations are illustrated in Figure 3, and Table 3 provides corresponding data of the number of rounds needed to achieve reliability levels of SSR = 0.8 and 0.9 with 80% probability. In this condition, it can be seen that having different levels of skewness in portfolio ability scores does not impact on the number of rounds needed have at least 80% probability of achieving reliability levels of SSR = 0.8 and 0.9. This suggests that the feasibility of ACJ is not tied to perceived ability level distributions within selections of portfolios.

Figure 3.
Results of ACJ simulations under various degrees of skewness in portfolio ability levels with logistically distributed disagreement. Each plot shows SSR per round (grey lines) and the average SSR per round (blue line) for 100 simulations. The amount of disagreement is described in Table 3.

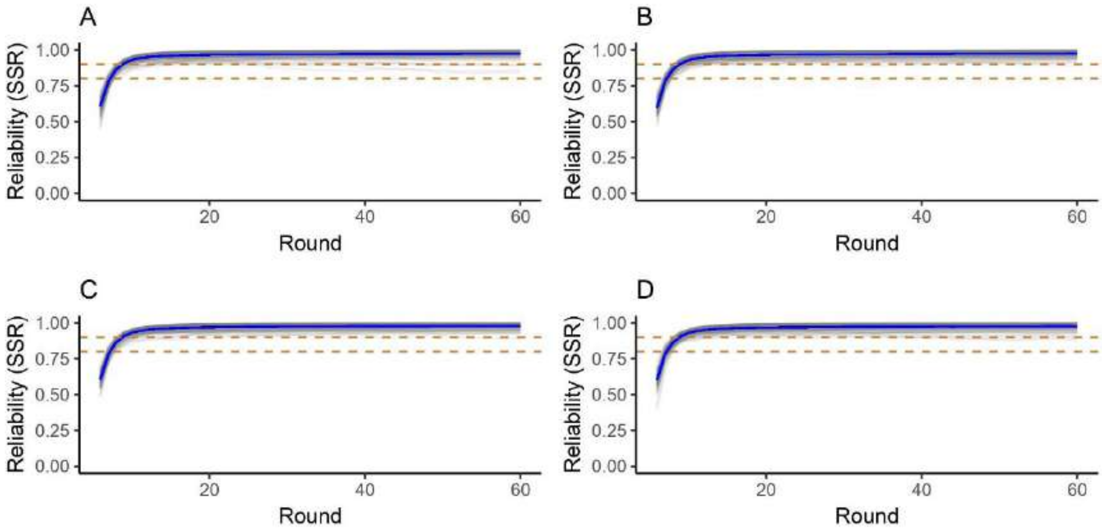


Table 3.
Results of ACJ simulations with varying degrees of skewness in portfolio ability levels with logistically distributed disagreement under various percentages of uniform disagreement.

Skewness	Figure reference	Rounds needed to achieve SSR > 0.8 with 80% probability	Rounds needed to achieve SSR > 0.9 with 80% probability
0.2	Figure 3A	8 (25% ← 99% → 100%)	10 (68% ← 87% → 92%)
0.4	Figure 3B	8 (31% ← 99% → 100%)	10 (67% ← 87% → 94%)
0.6	Figure 3C	8 (26% ← 98% → 100%)	10 (66% ← 89% → 94%)
0.8	Figure 3D	8 (31% ← 100% → 100%)	10 (60% ← 92% → 95%)

4. DISCUSSION

This work provides an initial set of simulations to provide indications of the feasibility of ACJ, using completely random rough sort rounds and a greedy algorithm for the adaptive rounds, described in terms of numbers of rounds or comparisons per representation required to have an 80% probability of achieving reliability levels of SSR = 0.8 and SSR = 0.9. What is unknown is what behaviours will be exhibited by assessors in reality, and how this behaviour would relate to the portfolios included in the ACJ session. This work is part of a larger simulation study which is more exhaustive in terms of differing real-world scenarios – such as there being multiple "groups" of judges making decisions based on different factors. For example, Buckley et al. (2022) observed that six criteria were used in making decisions by undergraduate technology teacher education assessors after a design activity. It is envisioned that subsequent work will involve the conduction of in-depth behavioural studies to determine assessor considerations when making comparisons in different technology education contexts (e.g., different assessors such as students and teachers and different types of activity). Such work could then be mapped onto these simulations as references for determining feasibility for continued ACJ usage. This would also need to be supplemented with similar insight into how assessors use rubrics. Despite a narrative literature search, there does not appear to be any investigation to date into time investments for rubric use, which would be a useful comparator for discussing ACJ feasibility. Further, this methodology can be used to determine more optimal algorithms to use to underpin the ACJ process. In this simulation study, the rough sort rounds were completely random, which is a different algorithm to the CJ algorithm used in the studies meta-analysed by Verhavert et al. (2019), and which is different again to the Swiss tournament approach suggested by Pollitt (in Kimbell et al., 2009). The adaptive algorithm used in this simulation study was a greedy algorithm, however this can be compared through simulation with an exact algorithm which is more globally optimal. Different numbers of rough sorting rounds can also be examined. However, running hundreds of simulations to produce a bank of potential realities as a reference does not seem to be the most efficient way to proceed. It would seem more useful to first determine judge behaviour in reality, and then using that information as a constant it would be useful to improve underpinning algorithm selection through simulation.

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Multiverse analyses as a tool to support analytical robustness in technology education research

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Abstract

Previous research in technology education has illustrated the need to increase transparency in how research is reported in technology education to improve credibility and enhance the repeatability of published works. Following the identification of a replication crisis is several social scientific fields, it became increasingly clear that analytic decisions made by quantitative researchers can have significant effects on observed results. The fact that making seemingly minor or arbitrary decisions whilst analysing data can impact results so much leads to two problematic scenarios. First, researchers may unknowingly produce unrobust results which are observed only by virtue of the analytic decisions they made rather than results which reflect reality or a broader population. Second, researchers may search through their data for a sequence of analytic decisions which provide a desirable result and report this without describing the entirety of the analytic process such that readers are unaware that the result is not robust.

In light of these possibilities, this work is presented under the assumption that if either of the above two scenarios is occurring in technology education research that it is the first. By using a multiverse analysis to reanalyse data from a previously published study, the robustness of results pertaining to a specific hypothesis is illustrated. In a multiverse analysis, a researcher can specify a series of choices to be made in an analysis, such as which variables can be included or whether sub-groups within the sample could be analysed separately, and then every possible scenario of decisions is examined. This process illustrates which results will be observed from particular analytic paths. Through this example, the multiverse analysis as a method for robustness checking is described and commentary is provided on the value of pre-registering research for increasing transparency within the quantitative technology education research literature.

Key Words: Research credibility, transparency, robustness, multiverse analysis.

1. INTRODUCTION: ROBUSTNESS AS A DIMENSION OF RESEARCH CREDIBILITY AND THE ROLE OF MULTIVERSE ANALYSES

Credibility in quantitative research has several dimensions. Vazire (2018) describes a credibility revolution in psychology and relates it to four themes including increasing research reporting transparency, encouraging preregistration of studies, conducting more replication studies, and adopting higher standards of evidence. This credibility revolution has been a response to what is commonly referred to as the replication crisis. This crisis was initially observed in psychology (Pashler & Wagenmakers, 2012), but has broadly become a concern in several other fields (cf. Anvari & Lakens, 2018). In technology education, there has not been any major observation of such a crisis. Although there have been few replication attempts to enable such an observation, there does not appear to be any discourse from within the field indicating awareness of or suspicion of an issue. That said, efforts to improve research credibility should not come only after an issue is observed. Ongoing credibility improvements should be the norm to both ensure trustworthy knowledge creation and dissemination and to mitigate any major problems. From this perspective, in technology education research there have been explorations into areas where research transparency can be improved in both quantitative and qualitative research (Buckley, Adams, et al., 2022; Buckley et al., 2024) and investigations into how replicable the field is (Buckley et al., 2021, 2023). Building on this work, this paper will focus the robustness of quantitative analyses through the lens of adopting higher standards of evidence. Specifically, this paper presents a description of how technology education researchers can use multiverse analyses – a method for analysing quantitative data – to improve the robustness of their work.

A robust result is one which is largely unaffected by decisions made when analysing a dataset. The opposite, a fragile result, is a result where the observation is dependent on the researcher making specific analytic choices. A fragile result is not necessarily incorrect, but it is a risk to the generalisability and replicability of the observation (Nosek et al., 2022). Several "Many Analysts" studies have revealed that the decisions researchers make when analysing data can have a significant impact on observed results (Botvinik-Nezer et al., 2020; Hoogeveen et al., 2023; Silberzahn et al., 2018). These decisions could relate to, for example, the treatment of outliers, the selection of parametric or non-parametric statistical tests, or the inclusion of covariates in models. In response to this issue, Steegen et al. (2016) introduced the multiverse analysis as a method to make these decisions explicit, and to determine the impact they have on a result. A multiverse analysis is an analysis where all such reasonable possible decisions are specified, and then all analyses across the set of decisions are performed. If, for example, a researcher had three decisions they could make in the analysis of their quantitative data, and for each of these there were two reasonable options, a multiverse analysis would involve analysing the data under the six possible combinations rather than the typical presentation of results from one approach to data analysis. This enables the robustness of a result to be seen by making clear whether there are dependencies on specific analytical decisions. Simson et al. (2024) present six steps to conducting a multiverse analysis, of which they note that the first four relate to multiverse analyses in general, and the fifth and sixth to larger multiverse analyses for algorithmic fairness:

Step 1. Identify plausible decisions
Step 2. Generate multiverse
Step 3. Traverse universes
Step 4. Examine variation across multiverse
Step 5. Calculate importance of decisions
Step 6. Examine important decisions in detail

Rather than discuss each step in detail, the following sections will present an exemplary vignette, illustrating the presentation of a single result for context and then demonstrating the value of a conducting a multiverse analysis with the same data.

2. EXEMPLARY VIGNETTE

The following three sections, called "Contextual introduction", "Contextual methodology", and "Contextual results and interpretation" are included here are as a precursor to a discussion on multiverse analyses. Readers should only engage with these sections to contextualise the subsequent sections.

2.1. Contextual introduction

Research on the role of spatial ability within technology education has grown in recent years (Buckley, Seery, et al., 2022). For example, the development of spatial ability through 3-dimensional modelling (Šafhalter et al., 2020) and educational robotics activities (Julià & Antolí, 2016), the relationship between the design process and spatial ability (Goktepe Yildiz & Ozdemir, 2020; H. Lin, 2016), and the location of spatial ability within technology syllabi (T.-J. Lin et al., 2023) have been investigated in recent years. This type of research has resulted in a view that spatial ability is important, and thus to research on the preparedness of secondary level teachers deliver an intervention to enhance spatial ability in learners (Benedicic et al., 2023; Maquet et al., 2023; Power & Sorby, 2021) and on integrating spatial ability development into technology teacher education programmes (Lane & Sorby, 2022).

The spatial training intervention developed by Sorby over the last three decades (Sorby, 1999, 2009; Sorby & Baartmans, 2000) has been proven to have a positive effect on the development of spatial ability in undergraduate engineering students (Sorby et al., 2018) and based on this is now being implemented in Ireland in a national study on its effectiveness at secondary level (Benedicic et al., 2023). One important use of this intervention currently in many US universities is that incoming engineering students who score below a certain threshold on the Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R: Bodner & Guay, 1997; Guay, 1977), a validated psychometric test of spatial ability, are offered Sorby's intervention with a view that this deficit in spatial ability needs to be rectified to support subsequent student success in their programme of study. There is a need to conduct research on this specific population – low spatial ability learners – in technology education with a view towards better supporting their learning.

2.2. Contextual methodology

Previous research in technology education by Buckley et al. (2019) examined the role of spatial ability in technology teacher education students performance in geometric problems. These problems were representative of the type of problems found within the Irish "Graphics" and "Design and Communication Graphics" subjects, subjects which are qualified as within the Irish suite of technology subjects at secondary level. Buckley et al. (2019) collected data on spatial ability through three validated psychometric tests and performance in geometric problems in a high-stakes formal examination. One of the geometric problems in the examination was contextually a geometric problem but required very limited technical knowledge to solve. It was essentially a contextualised spatial problem. As such, they coded how each student approached solving this problem specifically as an indicator of how they used or relied on their spatial thinking to solve the problems in the examination.

A reanalysis of the data presented by Buckley et al. (2019) was performed for this study. In this reanalysis, performance across the three spatial tests (the PSVT:R, the Card Rotation Test [CRT], and the Object Perspective Taking Test [OPTT]) were used to create a single composite score by first converting absolute performance to percentage scores and then taking the average (mean) performance across all three tests. This composite score was used as a single variable indicator of the student's spatial ability. Next, students were divided into quartiles based on their levels of spatial ability. Only the first quartile (bottom 25% of students) was of interest in this reanalysis due to the recognition of the need to study and support lower spatial ability students. A regression model was computed to see how predictive spatial ability was for performance on the geometric problem-solving examination, while controlling for a specific strategy used by students in the previously described problem – adding hidden detail. The reason for controlling for this variable was that by doing this the students could be augmenting the need to rely on spatial ability by not having to actually visualise the object in the first place, and this was taken as a general measure of their strategies for solving spatial ability dependent problems.

2.3. Contextual results and interpretation

The result of a regression model was that spatial ability, in these low spatial ability students, was a significant predictor of geometric problem solving performance when controlling for the use of hidden detail, however the effect was negative (β = -0.8922, $t(19) = -2.432$, $p < 0.05$). This finding indicates that for this group of students, having a higher level of spatial ability was detrimental to problem-solving performance. It is theorised that this group of students actually had insufficient levels of spatial ability in general and thus when trying to rely on this ability and implement a spatial approach to solving the problem they were not successful. The students who had lower levels of spatial ability likely did not even attempt a spatial strategy or if they did, they likely recognised that this was not useful for them and reverted instead to an alternative, possibly analytical, approach which ultimately resulted in greater success. From a pedagogical perspective this underscores the importance of metacognitive awareness in students such that they can reflect on their cognitive strengths and formulate approaches to problem-solving which align with their capacity. It is therefore recommended that cognitive tests could be used as a pedagogical aid in technology education to facilitate students being reflective in this way.

3. MULTIVERSE ANALYSES ARE A TOOL FOR QUANTITATIVE RESEARCHERS

The above exemplary vignette does not present a full account of a study as it would be presented if it were the empirical work being described, but it does contain the typical elements – an introduction to provide theoretical background, an account of a methodology, and results and interpretation. It is also a consistent narrative and, from a particular perspective, presents a reasonable interpretation and suggestion for future work. However, the result is a fragile observation. A multiverse analysis with the dataset was performed which determined this prior to the vignette being written. The vignette was written in the full knowledge of the result not being robust.

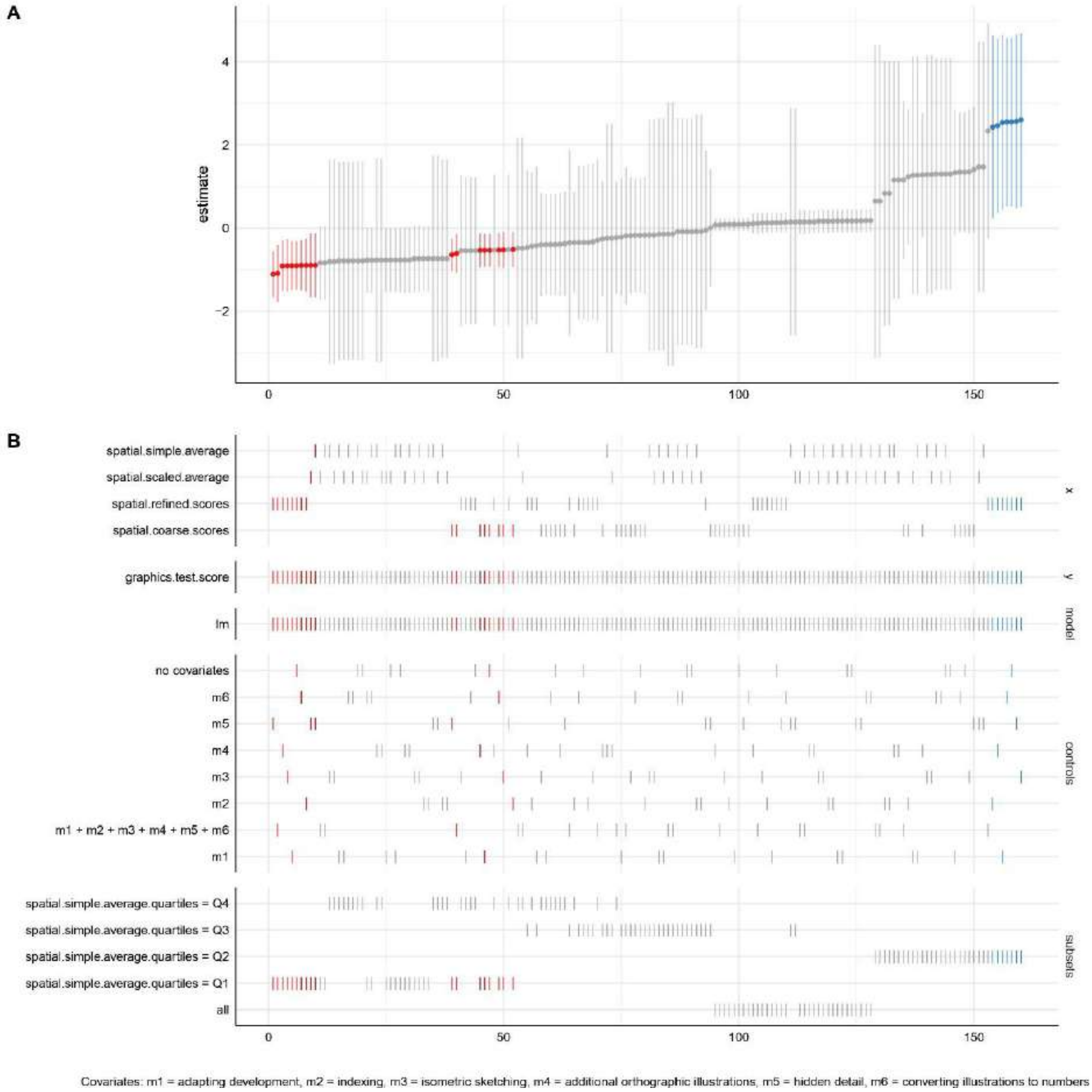
The dataset from the vignette does come from previously published work, but was treated differently in the original study (cf. Buckley et al., 2019). Data from three psychometric tests of spatial ability was collected and so too was performance data on a geometric problem-solving examination. However, the vignette suggested that only the strategy of adding hidden detail was a measured factor, when the actual dataset has observations for six different strategies.

The first step in a multiverse analysis involves deciding which plausible decisions could be made. In this case, the independent variable of spatial ability was a composite score. The vignette described the single approach used to create the composite score, a simple average score as this is a common approach, but there are other ways (cf. Moreau & Wiebels, 2021). For this multiverse analysis, the four ways described by Moreau and Wiebels (2021) were included, and the analysis considered all participants as well as each spatial ability performance quartile based on the simple average composite score. Performance on the geometry problem examination was included as the dependent variable, and the six different measured problem-solving strategies were each included as potential covariates. A linear model was then fit to the data. Based on these parameters, a total of 160 "universes" were explored in the multiverse analysis.

The results of the multiverse analysis are shown in Figure 1. Figure 1B shows which decisions were included in each analysis and Figure 1A shows the corresponding results. What is apparent is that there are few instances where a significant result is observed overall, and these only relate to negative relationships with the lowest quartile participants in terms of spatial ability level or to positive relationships with the second quartile of participants. Significant results are also only observed when the composite spatial ability variable is computed in two of the four included ways. From this multiverse analysis, it can now be shown that the earlier claim from the individual analysis presented through the vignette that in low spatial ability learners there is a negative relationship between spatial ability and performance in a geometric problem-solving examination is observable regardless of which problem-solving strategies are included as covariates, but only if the composite spatial score is determined by two of the potential four ways. If this were an article concerning the relationship between spatial ability and geometric problem solving in low spatial ability learners there would need to be a suitable conversation on the validity of the included composite score measures, but assuming for this article that they are all reasonable, the multiverse analysis illustrates that the observed result is dependent on an analytical decision. This indicates lower robustness than if the result was observed regardless of how the spatial ability composite score was determined.

The recommendation of this paper is that multiverse analyses would be a beneficial addition to technology education research simply to determine whether pre-processing analytic decisions are influential to observed statistical results. This does require researchers to consider what decisions could be reasonably made at this stage, from both analytic and theoretical perspectives, but is otherwise a very straightforward addition to researchers' analytic workflows. There is a negative potential use of multiverse analyses which is that it makes the questionable research practice of p-hacking easier, as a researcher could perform a multiverse analysis to see a way to present their analysis such that they could "observe" a desirable outcome. Given this potential adds further to the suggestion that, where relevant, multiverse analyses are incorporated by researchers as a check on the robustness of their observations.

Figure 1.
Multiverse analysis results



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A Qualitative Study of Technology Education in Quebec Textbooks: A Focus on Making

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Abstract

The current curriculum in Quebec integrates technology education with other scientific disciplines in a unique school subject called "science and technology" (S&T). Furthermore, textbooks play a crucial role in guiding classroom practices. They are approved by the Bureau d'approbation du matériel didactique to ensure compliance with the curriculum. Their importance lies not only in their impact on students' learning processes and understanding but also in the support they provide to teachers, especially those who have not been trained in technology or its teaching.

This study focuses on one of the technological contents prescribed in the program, "making," and analyzes how textbooks present technological concepts, design processes, pedagogical approaches, and the roles assigned to students and teachers. It also explores the links between these teachings and the context of learners.

This analysis deepens our comprehension of students' potential learning in technology and the textbooks' role in incorporating normative perspectives, including values and cultural perspectives, into classroom activities. In conclusion, the article proposes recommendations for future research and the development of effective educational resources to enhance technological education in the Quebec curriculum.

Key Words: Technology Education, making, Design Processes, Textbooks analysis.

1. INTRODUCTION

1.1. Technology in Quebec Education Program

The current Quebec Education Program (QEP) (2007) serves as a comprehensive guideline for educational objectives for students in Quebec, Canada. Within the curriculum, the S&T program is designed to nurture students' scientific and technological literacy, critical thinking abilities, and problem-solving skills. The QEP encompasses several key components: competency-based approach, hands-on learning, inquiry-based learning, interdisciplinary connections, project-based learning / Investigation, Technology Design Process, and ethical and environmental considerations. By incorporating these key components, the QEP aims to provide students with a well-rounded education that prepares them to be scientifically and technologically literate, and problem solvers in an ever-evolving world.

In Quebec, teachers have a multifaceted role that encompasses various important responsibilities. Firstly, teachers act as facilitators of learning, guiding their students through engaging hands-on activities, experiments, and projects. They are also responsible for implementing the curriculum in their classrooms. Additionally, they play a crucial role in assessing their students' progress and understanding. Emphasizing ethical and environmental considerations in their teaching is another key aspect of their role. Moreover, they should collaborate with colleagues from different subjects to create interdisciplinary learning experiences for their students. Finally, they should adapt their instruction to meet the diverse needs of their students.

1.2. Technological Making

The integration of Maker Movement within formal education has captured the attention of researchers and practitioners alike. The Maker Movement, known for its emphasis on hands-on learning through crafting and tinkering, has emerged as a powerful educational approach (Gershenfeld, 2005).

Moreover, the introduction of digital fabrication in education, which allows for the creation of physical objects, has a positive impact on technology education. When combined with the principles of the Maker Movement, this technology provides students with opportunities to engage in creative problem-solving, design thinking, and innovation. By integrating these practices into the curriculum, students not only learn to use advanced technological tools but also develop a deeper understanding of scientific and engineering concepts (Martin, 2015).

Scholars have observed that the Maker Movement fosters inclusivity in learning environments by making technology accessible to a wider audience (Martin, 2005). The hands-on, participatory nature of making activities, can demystify technology for students who may feel alienated by traditional lecture-based instruction. This accessibility helps bridge the gap between those with and without prior exposure to technology, promoting inclusivity and equal opportunities for technology-driven innovation.

Practitioners have also noted that Maker activities promote essential 21st-century skills, including collaboration, communication, and critical thinking (Halverson & Sheridan, 2014). Making in educational settings encourages students to take ownership of their learning, engage in iterative design processes, and collaborate on solving complex problems.

Besides, the implementation of makerspaces within schools provides students with a tangible context for learning. These technological workshops democratize access to fabrication tools, enabling students from diverse backgrounds to experiment with and create innovative solutions (Gershenfeld, 2005). Makerspaces serve as incubators for creativity and technical skill development, empowering students to become active creators rather than passive technology consumers. By integrating the principles of making, digital fabrication, and the Maker Movement into education, we foster a dynamic learning environment that nurtures creativity, problem-solving, and technological literacy.

1.3. Role of Textbooks

According to Malcolm and Alant (2004), textbooks play a crucial role in schools where teachers may have limited content knowledge and planning skills, and where students are expected to engage in independent work. These textbooks serve as valuable sources of knowledge, curriculum planning, and teaching ideas for both educators and students.

In the context of technology education, textbooks play a significant role in shaping the teaching and learning process. They are supposed to provide quality and structured content, clear explanations, and relevant exercises and activities that effectively support the learning objectives. By offering a comprehensive framework, textbooks assist teachers in delivering engaging and impactful instruction, while providing students with a scaffolded learning experience.

In his study, Swanepoel (2010) highlights the important role of textbooks in S&T education. According to his analysis, textbooks serve multiple purposes, including delivering standardized and accurate content to students, aligning teaching with curriculum standards, providing pedagogical support, acting as a resource for teachers, and influencing student learning outcomes. Studies worldwide indicate that textbooks continue to be widely used (Lemmer et al., 2008; Swanepoel, 2010) and are considered crucial for effective instruction (Taylor, 2008), as shown in table 1. These studies have measured the prevalence of textbook use, demonstrating their ongoing significance in educational settings. Another significant benefit of learning from textbook is that it equips learners with the skills and mindset necessary for lifelong learning.

Table 1.
Examples the use of textbooks (Swanepoel, 2010, p 56)

Country	Research on textbook use
USA	▷ 96% of grade 9–12 science classes use published textbooks ▷ 59% of a national sampling of science teachers indicated that textbooks had a major influence on their teaching *(NSTA, 2003)*
France	Teachers use textbooks almost all the time (Pepin and Haggerty, 2003)
Germany	▷ 70% of teachers used mostly textbooks ▷ 20% of teachers used textbooks often ▷ 8% of teachers seldomly used textbook ▷ 2% of teachers never used textbooks *(Sitte, 1999)*
Austria	▷ Textbooks are the most used teaching aid. Textbooks were used in 87,4% of the cases where teaching aids were used *(Sitte, 1999)*.
Spain	▷ 92% of teachers use textbooks as basic reference for planning *(Huber and Moore, 2001)*

From Table 1, we can see that different countries have different approaches to textbook provision and use. In France, where teachers use textbooks almost all the time, it is regarded as vital to provide students with textbooks, while in Germany, where 70% of teachers use mostly textbooks, pupils are expected to buy their own textbooks (Tyson, 1997).

In Quebec, similar to France, the practice of providing textbooks to all students is followed. Teachers enjoy the autonomy to select textbooks that they believe best align with their teaching methods and meet their students' needs. These textbooks are distributed to students at the beginning of each school year and collected at the end to be passed on to the next cohort, ensuring that students have the essential resources necessary for their studies. Schools normally purchase textbooks at the start of each curriculum reform (2006 for the current secondary curriculum). Publishers produce these textbooks only once for the entire duration of the curriculum. This emphasizes the critical role of selecting appropriate textbooks. It is crucial to acknowledge that curriculum reform not only changes what is taught (content) but also how it is taught (approaches) (Powell and Anderson, 2002). This presents a significant challenge for teachers, as they bear the responsibility of assessing the quality of the textbooks during the selection process.

As noted by Ansary and Babaii (2002), expecting unqualified and inexperienced teachers, who have not received any training in textbook evaluation, to independently determine the quality of a textbook without proper guidance is unrealistic. Consequently, unqualified and inexperienced teachers may struggle to make informed choices when selecting textbooks, often relying on superficial factors such as the quality of images, figures, and printed paper. Another main issue in Quebec education system is that schools must cope with the selected textbooks throughout the entire duration of the curriculum reform period, which typically spans an average of 20 years. This means that once a textbook is chosen, it remains in use by schools for an extended period of time. After the selection, teachers often depend heavily on the chosen textbook for planning and delivering their instruction (Lemmer et al., 2008). Unfortunately, some educators may over-rely on or misuse textbooks, leading to ineffective teaching practices (Klassen, 2006). In some instances, textbooks are used merely to maintain classroom order by keeping students occupied (Brändström, 2005).

Furthermore, excessive reliance on textbooks can promote passive learning experiences. Ninnes (2002) notes that the way teachers use textbooks significantly influences how students engage with these resources and their understanding of scientific epistemology. Additionally, Alexander and Kulikowich (1994) found that a rigid adherence to textbooks can foster the misconception that S&T are merely a collection of facts presented in the textbook, reinforcing a dogmatic view of these subjects.

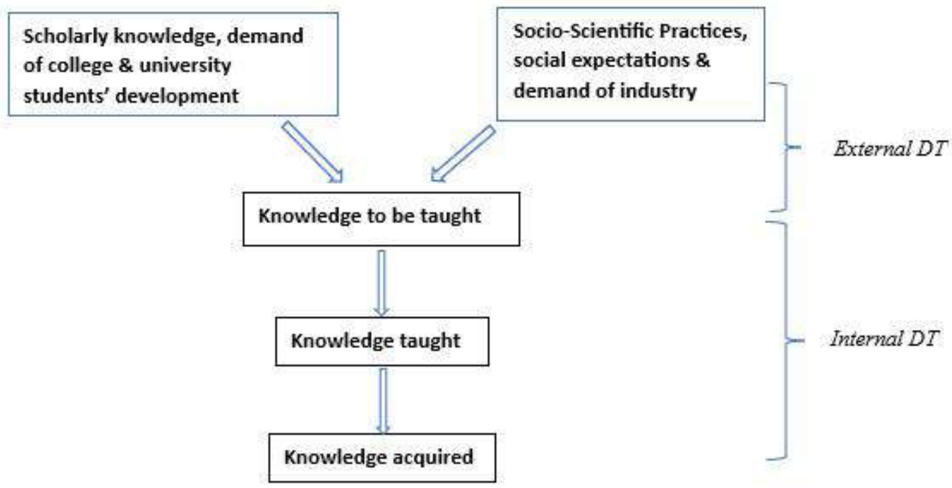
1.4. Didactic Transposition

When Chevallard (1985) introduced the concept of "Didactic Transposition" (DT), which is equivalent to "curriculum adaptation", he was concerned with the selection of knowledge to be taught. Operationally, DT can be seen as the process through which scholarly knowledge is transformed to make it suitable for use as learning materials.

Moreover, several researchers emphasize that scholarly knowledge is just one resource among others for developing school programs. There are disciplines and teachings where the reference knowledge is not scholarly knowledge, such as technology education and arts education (Clerc, 2006). It is within this logic that Martinand (1986) introduced the concept of Socio-Scientific Practices (SSP). These refer to all social activities that serve as a reference for constructing knowledge to be taught. SSP also provide a tool for reconsidering school activities by comparing them with the real-life activities they aim to reveal.

Pedagogically speaking, for the teaching of a technology concept to be legitimate, it must reflect what is accepted as constituting engineering and technology today. There must be a minimal "resemblance" between the knowledge taught and scholarly knowledge or SSP. Resemblance means that the knowledge taught must be reshaped according to pedagogical requirements, but it must still "resemble" scholarly knowledge/SSP or else it risks being accused of obsolescence (Philippe, 2004). To illustrate the DT process, figure 1 presents a modeling in four levels.

Figure 1
Steps of Didactic Transposition (Source: El Fadil, 2021)



The external level refers to society in terms of scholarly knowledge and SSP. The first internal level, knowledge to be taught, refers to the legislator who selects the knowledge and SSP that seem most relevant to teach and translates them into a training curriculum, then into a textbook. Thus, the textbook serves as a medium through which the intended curriculum is transposed into the adopted or implemented curriculum that is actually experienced in the classroom. It acts as a bridge, connecting the written curriculum to the practical application of educational content and objectives. In essence, the textbook is a result of a process of DT of the curriculum statements.

However, as noted by Develay (1992), each transition from one level of DT to another results in a loss of knowledge. Consequently, the textbook represents only a partial translation of the curriculum, as interpreted by the authors (Chaachoua, 2009). At the second level of DT, teachers rely on the textbook to select a specific knowledge and plan their teaching activities. This approach transmits only part of the curriculum, emphasizing what appears most important for teachers. Thus, the teacher translates the curriculum into a form of recipe ready to be applied in classroom and decides what, how, and why to learn (McComas, 1998). At the final level of DT, we reach acquired knowledge. Ultimately, the students assimilate only part of what the teacher intends to teach them. As for the transformation of knowledge from one level to another, several authors emphasize that school knowledge is not organized in the same way as scholarly knowledge (Thouin, 2009). Therefore, the problems addressed in S&T with students and the relationships established between the different concepts taught differ from the problems and relationships that concern scientists. When inadequate, the transformation between the two types of knowledge can take, among other things, several of the forms synthesized in Table 2 below.

Table 2.
Risks of a poorly successful Curriculum Adaptation or DT (adapted from Audigier, 2009)

Form	Description
Dogmatism	It refers to the tendency to adhere rigidly to certain beliefs or principles without questioning or considering alternative perspectives. Dogmatism involves an unwavering conviction in one's own beliefs, often without empirical evidence or critical evaluation.
Depersonalization	It refers to a state or experience in which an individual feels detached or disconnected from their own thoughts, feelings, or sense of self. Depersonalization can manifest as a sense of observing oneself from a distance or feeling like an outside observer of one's own thoughts and actions.
Desynchronization	It refers to the process of breaking down or dismantling a previously established synthesis or integration. It involves a separation or fragmentation of previously unified elements or concepts.
Excessive operationalizat	It describes the act of overly specifying or defining operational procedures or criteria in a research or theoretical framework. Excessive operationalization can result in an overly complex or convoluted process, potentially hindering clarity and practicality.

Research Questions

(i) How do Grade-10 Science and Technology textbooks integrate making activities to promote technological processes and learning?
(ii) What pedagogical strategies and content are emphasized in technology education textbooks that incorporate making as a central component of the Technology Design Process?

2. METHOD

In countries where multiple textbooks are available, it is important to select those most commonly used by teachers. Inspired by studies focused on the analysis of science textbooks (Li et al., 2020), we selected two grade-10 textbooks: (1) Synergie – ST (2008), referred to as Collection A, and (2) Observation (2010), referred to as Collection B.

The reasons for choosing these two collections are based, on one hand, on their approval by the Ministry of Education. It is worth noting that other collections have been approved by the Ministry, but the two selected meet the textbook selection standards highlighted in the Pingel (2010) study (representativeness, approval and use, and geographical coverage). On the other hand, the 10th-grade level constitutes the last year of compulsory technological education

To analyze the textbooks, we used a content analysis approach based on Krippendorff (2018) method. Generally, the phases of such an analysis include pre-analysis, material exploration, result processing, inference, and interpretation.

First, we began our analysis with exploratory readings aimed at systematizing the original analytical framework. Next, we proceeded to categorization. Additionally, we developed an analysis grid (see Appendix A), taking into account not only the problem dimensions and criteria outlined in Swanepoel (2010) but also other contextual elements.

3. RESULTS AND DISCUSSION

To provide readers with a comprehensive understanding of the Technology Education Curriculum in the QEP, we initiated our analysis by examining the entire unit dedicated to Technology. This approach allows us to gain valuable insights into the curriculum's scope and objectives. By exploring the Technology unit in detail, we can better understand the role of making in relation to the knowledge and competencies it aims to foster among students.

All S&T textbooks in Quebec are categorized into four parts: Material World, Living Thing World, Earth & Space, and Technological World (TW).

In collection A, TW is organized in chapter 4, which is further subdivided into six sections. This chapter spans across a total of 110 pages, as shown in Table 3.

Table 3.
Structure of TW in collection A

Section	Focus	Description	Announced objectives
1	**Language of Lines**	Covers fundamental concepts and principles related to graphical representation in technology	Explore basic conventions that govern technical drawing
2	**Mechanical Engineering):**	Explores the principles and applications of mechanical engineering, including machines, mechanisms, and systems (motion transformation and transmission).	Deepen your understanding of transmission and motion transformation systems, as well as speed changes. Explore new features related to the linkage and guidance of parts in motion.
3	**Electrical Engineering**	Examines basic concepts and techniques in electrical engineering, including circuits, electronic components, and electrical systems	No objective announced
4	**Materials**	Focuses on various materials used in technology, such as metals, plastics, wood, and composites, including their properties, transformation processes, and applications.	No objective announced
5	**Making**	Addresses the applications of technology in biotechnologies, including genetics, bioengineering, and other advancements in the field.	Explore the various operations involved in the manufacture of technical objects
6	**Biotechnologies**	Addresses the applications of technology in biotechnologies, including genetics (cloning), biodegradation of organic pollutants, and water treatment.	Explore three biotechnologies: water treatment, biodegradation of pollutants, and cloning

In collection B, the TW is organized in a section that is subdivided into three chapters: Chapter 12, Chapter 13, and Chapter 14. This section spans across a total of 101 pages, as indicated in Table 4.

Table 4.
Structure of the TW in collection B

Chapter	Focus	description	Announced objectives
12	**Making**	It encompasses various aspects related to materials, drawing, machine-tools, and techniques.	Objectives formulated as questions: What materials are most often used to make objects? What types of drawings are commonly used to determine part shapes? What are the main manufacturing techniques, and what tools and machines are used for the production of objects?
13	**Mechanical Engineering**	It aims at the design and analysis of new technological systems, focusing on linkage, guidance, motion transmission and transformation systems, as well as speed changes.	How can we link and guide the movements of mechanical systems? Can movements be transferred from one part to another? Can we change the speed or nature of a movement?
14	**Electrical Engineering**	Examines basic concepts and techniques in electrical engineering, including electric circuits, electronic components, power supply function, Conduction, insulation, and protection functions.	What are the components needed to build electrical and electronic circuits? What are their functions? How do you choose and assemble them?

Table 4 and table 5 show that the two collections provide almost the same content. The main difference between the two collections lies in the placement of the biotechnology chapter. Collection A includes it within the technology chapter, while Collection B positions it in the 'Living Things World' section.

Regarding objectives, the collection B clearly states the objectives of each chapter in the form of questions, whereas collection A outlines objectives for sections 1, 2, 5, and 6, but does not provide objectives for sections 3 (Mechanical Engineering) and 4 (Materials). A preliminary analysis of the two collections shows that the content is presented in an encyclopedic manner (see excerpt 1, in appendix B), suggesting that the emphasis is on memorization as a learning approach. The omission of objectives in certain chapters or sections may reinforce this assumption.

Furthermore, a content analysis of the textbooks suggests that the presentation of technological concepts and procedures primarily focuses on vocabulary acquisition and the memorization of definitions. Both collections lack comprehensive explanations of technological knowledge, procedures, and their origins or contextual applications. Additionally, both textbooks include a glossary at the end, providing definitions for commonly used words and expressions in scientific and technological fields as defined by the authors.

However, it is crucial to recognize that a purely encyclopedic approach to knowledge listing is not the most effective way to facilitate learning. Educators should shift their perspective from solely understanding "what scientists know" to comprehending "how scientists know" (McComas, 1998). This shift in perspective emphasizes the importance of scientific and technological methods in the construction of new knowledge.

By incorporating explanations of scientific and technological processes, their applications, and the reasoning behind them, educators can foster a deeper understanding of the subject matter. This approach encourages students to actively engage with the material, promoting critical thinking, problem-solving skills, and the ability to apply knowledge in real-world contexts.

The analysis of the exercises and activities at the end of section 5 (making) in collection A confirms this finding. Indeed, at the end of the section, 15 exercises were provided (Table 5).

Table 5.
Nature of exercises at the end of section 5 (Making, collection A)

Making Concepts	Exercises
Shaping	4 questions: all of them are about name an object or a procedure.
Making	6 questions: 4 are about memorization and 1 is What is drilling in technology, and why is it used in manufacturing? And 1 is Why are there drill bits with different heads and angles?
Instrumentation and control engineering	5 questions: 2 are WH-questions (why it is important to measure? Why accuracy is important? 3 are which-questions.

According to the data in Table 5, it is evident that out of the 15 exercises, 12 focus on memorizing concepts, tools, and procedures (see excerpt 2, appendix B), while only three aim at promoting understanding. This finding aligns with Dolan's (2009) observation that science and technology courses often face criticism for seemingly burdening students with irrelevant memorization of information that lacks practical relevance in their lives. This result is not surprising and is consistent with the findings of previous studies that have examined textbooks (Li, et al., 2020).

Regarding the collection B, the textbook offers a total of 14 questions, along with 1 synthesis-based question, at the end of chapter 12, which covers the topic of making. For specific details of this analysis, please refer to Table 6 for a comprehensive overview.

Table 6.
Nature of exercises at the end of section 5 (Making, collection B)

Making Concepts	Exercises
Materials and their mechanica properties	6 questions: 4 (1, 3, 4 & 6) are about name the constraint or treatment or matching. 2 of them aim at understanding (2 is about understanding mechanical properties; 5 is about application of scientific knowledge in engineering)
Technical drawings	4 questions: 2 are about memorization, 1 is about object analysis approach? And 1 is about understanding dimensioning and dimensional tolerance in technology
Making: tools and technics	4 questions: all of them focus on memorization
synthesis-based question	This question starts by showing a picture about a tool and asks questions about the material required to make it, mechanical properties of this material, the use of heat treatment, drawing, machine-tools, and asks students to summarize the chapter in the form of a conceptual mapping

According to Table 6, it is evident that in Collection B, understanding of technological concepts is primarily associated with memorization as well. Of the 14 exercises analyzed, 10 emphasize memorization. This approach reflects a teaching method known as excessive operationalization, where the emphasis is placed on memorizing procedures, techniques, and tools rather than providing in-depth explanations of technological principles (McComas, 1998). Consequently, students may perceive technological knowledge at school as being restricted to secondary aspects of scholarly knowledge, focused on memorization rather than hands-on learning and problem-solving approaches (Wang & Hannafin, 2005). This finding underscores the need to reconsider instructional strategies to foster a deeper understanding of technological principles and to promote practical and critical thinking skills in students (Barker & Camacho, 2010).

In S&T, knowledge is not approached as fixed truths or facts listed in a textbook, but as sets of activities that model real-life scientific, technological, or professional practices (Bengloan & Nichele, 2012). Surprisingly, both collections present technological learning as a set of established truths, thereby exercising a form of dogmatization. This approach prevents students from understanding the historical and human progression of technological processes. Despite both collections being labeled as student textbooks, learners cannot effectively use them without the assistance of an expert. Aside from the exercises at the end of chapters or sections, the textbooks lack additional activities for students. Our analysis also reveals a lack of activities focused on collaboration, problem-solving, and the interrelation between technology and sustainable development as well as a complete absence of cultural integration in manufacturing. Notably, there is no indigenous perspective included in either the texts or the sidebars. As a result, students are unlikely to effectively apply technological processes, develop critical thinking skills, or integrate equity, diversity, and inclusion. To facilitate constructive learning, it is highly recommended that textbooks provide ample opportunities for activities that promote cognitive engagement, encourage collaboration among students, and create the conditions necessary for conceptual change to occur. By incorporating these elements, textbooks can transform into powerful tools that not only support active learning but also facilitate deeper understanding among students. By actively engaging with the content through activities and collaborative work, students are encouraged to think critically, apply their knowledge, and develop a more comprehensive understanding of the subject matter.

5. CONCLUSION

The analysis of the selected textbooks reveals both strengths and areas for improvement in integrating hands-on activities and fostering technological literacy in students. Although the QEP emphasizes a competency-based approach, with a focus on hands-on learning, inquiry-based learning, and project-based learning, the examination of these textbooks shows that, while they are effective in delivering structured content, they do not fully align with the QEP's objectives.

Textbooks often emphasize memorization of technological concepts and procedures over deep, experiential learning. The heavy focus on rote learning and the lack of context in defining technological processes may limit students' ability to grasp the underlying principles of technology design and problem-solving. To address these issues, it is crucial to refine the integration of hands-on activities, as required by QEP, within textbooks and enhance the focus on understanding technological processes rather than mere memorization. By doing so, educators can better support the QEP's vision of developing students' critical thinking, and problem-solving skills. It is obvious that current textbooks cannot fulfill their important function in addressing the problem of collaboration, motivation integration of STEM activities, incorporation of indigenous perspectives and the problem of inadequately qualified teachers.

In summary, the analysis of technology content in textbooks reveals several issues that warrant further exploration:

(i) Curriculum changes: significant updates and expectations in the curriculum mean existing textbooks may no longer align with new educational standards, objectives, or content.
(ii) Pedagogical advances: advances in educational research and pedagogy may necessitate a change in textbooks.
(iii) Technological integration: with the increasing use of technology in education and real life, along with the publication of the Digital Action Plan for Education (2019), textbooks may need to be updated to include digital resources.
(iv) Cultural and social relevance: unlike some other Canadian provinces such as Ontario and British Columbia, the Quebec curriculum does not currently include a specific focus on indigenous knowledge in subjects like science, technology, or mathematics.

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Engaging Underrepresented Minorities in STEAM Through Indigenous Stories

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Abstract

In this article, the authors report on a case study where we engaged underrepresented minorities in Science, Technology, Engineering, Art, and Mathematics (STEAM) by retelling indigenous stories from the South Pacific. In this study, the authors taught the students how to retell two existing Indigenous stories through coding in Scratch. First, we conducted a pre-exposure test of the student's perceptions of STEAM subjects using a child-friendly Likert scale from an adapted version of an existing survey instrument. The students were taught how to retell indigenous stories using Scratch for the following seven weeks. After the completion of the lessons, the students were given the same survey to assess any changes in perceptions of STEAM subjects. We incorporated two additional questions to assess interest in additional lessons and future careers in STEAM. The key findings were a positive change in perceptions of STEAM subjects. We also asked the classroom teachers to reflect on the experience, and they reported high levels of engagement and interest in STEAM.

Key Words Underrepresented minorities, Indigenous stories, STEAM Education, Computational Thinking, Scratch

1. INTRODUCTION

The participation of underrepresented minorities in STEM or STEAM subjects has garnered considerable interest (Chen et al., 2017; Fowler & Cusack, 2011; Kafai, 2006; May & Chubin, 2003). In the context of this paper and the two schools we worked with, we are referring to Māori and Sāmoan students, when we speak of underrepresented minorities. While many students from underrepresented minorities demonstrate an interest in STEM subjects at an early age, that interest dissipates when decisions are made about careers or further study (Kniveton, 2004). Structural and social issues influence these decisions and strongly influence career choice (Seligman et al., 1991). Given the social, economic, and cultural advantages STEM graduates enjoy, the underrepresentation of minorities in STEM subjects perpetuates inequalities, including those which potentially violate the principles of the Treaty of Waitangi (Kēpa & Manu'atu, 2011).

Due to the lack of Māori engaging in STEM subjects focusing on underrepresented minorities in STEAM is necessary regarding social justice and equity. The benefit of increasing representation and the skill sets of underrepresented minorities will increase representation and products and services that represent the diversity of Aotearoa, New Zealand. The other benefit of increasing representation is that future generations will identify with the success of role models they can identify with and feel empowered to follow them.

With the increased growth in STEM careers, the demand for qualified staff has also increased (Hurtado et al., 2010). However, the rise of this vital sector has not addressed a major issue of representation of underrepresented minorities by gender, ethnicity, or family income. Not only does this represent an equity or equality issue, but it also potentially creates product or service homogeneity. Improving gender and cultural diversity in the workplace can impact product diversity and representation (Ferrini-Mundy, 2013; Nelson, 2014; Tsui, 2007).

Many young students from underrepresented minorities demonstrate an interest in STEM at an early age. However, this, for several reasons, dissipates when decisions about careers or further study are made. Some of the core reasons identified in the literature can be categorised as internal or external causes. External factors can influence internal causes such as self-confidence and perceptions of ability but strongly influence career choices (Bandura, 1994; Barron & Gravert, 2022; Basow & Howe, 1980; Hackett & Betz, 1995). The external causes can be categorised as social or environmental. The social factors influencing these decisions are family, peers, teachers, and school counsellors (Si'ilata, 2014; Webber, 2024). The environmental factors include the location (the availability of STEM programs) and access to libraries, museums, or connectivity and curriculum.

To address these challenges, the authors developed a series of modules connecting to the New Zealand Curriculum (Ministry of Education, 2017) to engage students in STEAM/STEM subjects and investigate the effectiveness of the modules in engaging students.

2. RESEARCH QUESTIONS

This study aims to investigate the impact of an intervention to increase perceptions and persistence in STEM/STEAM subjects, with researchers positioned as insider/outsider. Allan Fowler and Angus Campbell are Senior Lecturers in the Faculty of Creative Art and Industries. Ruth Lemon, as Māori educator, Yasmin Dullabh is a Bachelor of Design student in the Faculty of Creative Arts and Industries.

- How effective are the modules at engaging underrepresented minorities in STEAM?
- To what degree do the modules affect the perceptions and persistence of STEAM?
- How effective were the modules for the teachers?

3. LITERATURE REVIEW

The existing literature relevant to this study includes existing research into computational thinking, the use of block-based systems (like Scratch) to introduce your students to programming/coding, and how indigenous stories have been used to engage students in STEM/STEAM.

3.1. Computational Thinking

Seminal author on computational thinking (CT) Jeannette Wing (2012) highlights that with the ubiquity of computers and computing, computational thinking will be a fundamental skill used by everyone in the world by the middle of the 21st Century. Wing (2006) notes the following characteristics of CT:

- Conceptualising, not programming.
- Fundamental, not rote skill.
- A way that humans, not computers, think.
- Complements and combines mathematical and engineering thinking.
- Ideas, not artifacts.
- For everyone, everywhere (p. 35).

Six years later, Suchi Grover and Roy Pea (2013) explore the state of CT in K–12 education. They note that there has been significant work on defining the concept of and developing tools for CT (Grover & Pea: 42). However, they note that there is still work to do in considering how CT can be situated socio-culturally, how computing can be used to teach other subjects, and how gender biases of computing can be overcome. An Expert Advisory Panel was set up in 2020, with the goal of providing an independent source of expertise to the Ministry of Education on improving teaching, learning and assessment in the Technology learning area (Royal Society Te Apārangi, 2021). Our study was designed to address these needs.

3.2. Block-based systems for learning programming/coding

Diana Pérez-Marín et al. (2020) explore how computational learning can be improved using a methodology based on metaphors and Scratch to improve computer programming skills in primary education children. Their study is not focused on changing students' perceptions of STEAM but was inspirational in using metaphors like stories to develop CT. In addition, building on the work of Jesús Moreno-León et al. (2015) and LeChen Zhang and Jalal Nouri (2019), Pérez- Marín et al. (2020) found that "Scratch is useful for... improving students' CT" (p. 9). This led to our choice of Scratch as the medium of learning within the modules in this study (See Lemon et al., 2023 for a related study focusing on Tangible User Inputs or TUIs and their role in teaching programming with young children). Yauney and Bartholomew (2023) found that introducing computer science (or coding) into the classroom was beneficial, as students perceived the topic as being fun and provided potential employment prospects.

3.3. Indigenous stories in STEM/STEAM

Qingna Jin (2021) undertook a systemic literature review of how indigenous students were supported in science and STEM education in 24 international studies. "All the programs had reported positive outcomes with Indigenous students' science learning, understanding of their own cultures and traditions, and the complementarity of Western science and Indigenous knowledge."

(Jin, 2021:1). This study was design to expand on the existing literature on using indigenous storytelling to engage students in STEM (Lemon et al., 2023; Moeke-Maxwell et al., 2020). However, in this study, the authors sought to incorporate the intervention in a classroom environment

Hon (2015) curated Eye Hand Mind: Seeking, Making, and Understanding at the FADA Gallery in Johannesburg in collaboration with Africa Meets Africa (AmA). The exhibition practically explores how "learning departs from what is known" (Hon, 2015.). Showcasing the work of master artists and craftspeople, the exhibition presents a "unique art skills-based learning methodology, which integrates the subject's Visual arts, History and Mathematics within the requirements of the national CAPS curriculum." (Hon, 2015). This methodology enables high school students to learn abstract mathematical concepts of geometry with their eyes, hands and minds as they copy the styles of familiar southern African weaving and beadwork from art Masters within their communities. AmA's approach supports students towards higher education through a STEAM-based approach accessible to the students but also ensures that indigenous knowledge endures. A similar STEM-Art-based approach focused on indigenous storytelling to support Native American students practically learning robotics is documented in a chapter by Tzou et al. (2020). Zhang (2021) also explores how indigenous digital storytelling can activate students' development of self-representation and decolonial learning in library maker spaces in Canada. All these projects evidence the efficacy of indigenous storytelling and creative making as effective ways to support STEAM subjects' learning for underrepresented minorities.

4. METHODOLOGY

4.1. Population

To determine if these modules would improve interest and participation in STEAM, the authors recruited two Primary Schools in Auckland, New Zealand. Due to the focus of the study, a convenience sampling method was used. The authors obtained ethics approval from the University of Auckland Human Ethics Committee (Approval # UAHPEC23858). We then met with the school administration and classroom teachers to discuss how to implement this trial in the classroom. With the teachers' help, we could trial the intervention in five classrooms (N=124).

4.2. Data Collection

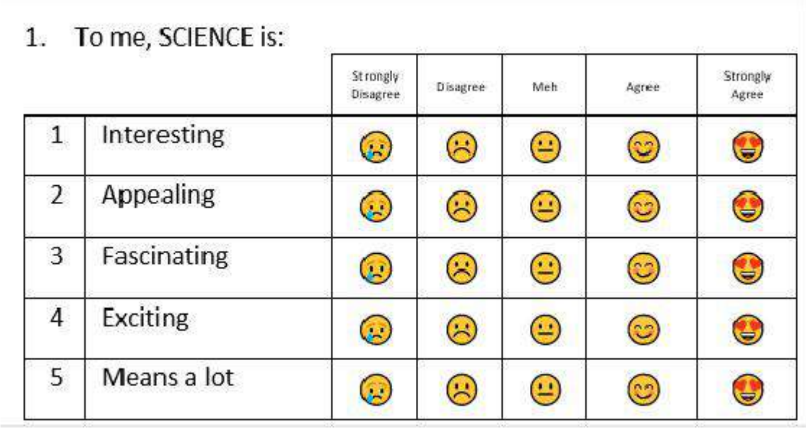
The authors and the teaching team co-developed a series of modules based on the New Zealand curriculum framework to engage students and address the challenges of the lack of engagement in STEAM subjects. The first two modules engaged the students in retelling indigenous stories in Scratch (Resnick et al., 2009) to improve literacy and numeracy. The third module involved the students imagining their future using Minecraft Education Edition (Microsoft, 2023). The third module was developed to help students improve literacy through retelling indigenous storied. The students used laptops to create the code to incorporate the technology aspects.

The modules engaged the students in aspects of science (navigation), technology (design to meet a need), engineering (structures), and mathematics (coordinates, calculating, and distances). The students also created sounds, modified sprites, and incorporated music into their stories.

In the first module, students were asked to retell how Nukutawhiti re-discovers Aotearoa using Scratch. The second story involved students retelling a story from Samoa, where a mother and son drowned in the ocean. The story was provided by one of the classroom teachers who is originally from Samoa. In both projects, the students were given the sprites and then taught to code each part of the story. Finally, students were asked to design what their school would look like in one hundred years, and this time, they used Minecraft Education (Microsoft, 2023).

To understand how effective the modules were at improving perceptions of STEAM subjects, we used a survey instrument to evaluate changes in the students' perceptions. We developed pre- exposure and post-exposure instruments to help measure these changes. The pre-exposure survey instrument was administered on the first day before the delivery of the curriculum content, and the post-exposure survey instrument was administered on the last day. From our experience in the field, we found that younger participants struggle to understand a Likert scale or how to indicate their responses accurately. Therefore, we developed a survey instrument using a child-friendly Likert scale (Smileyometer) (Read & MacFarlane, 2006) for the students to complete (Figure 1).

Figure 1.
Smileyometer (Read & MacFarlane, 2006)



1. To me, SCIENCE is:

		Strongly Disagree	Disagree	Meh	Agree	Strongly Agree
1	Interesting	😢	☹️	😐	😊	😍
2	Appealing	😢	☹️	😐	😊	😍
3	Fascinating	😢	☹️	😐	😊	😍
4	Exciting	😢	☹️	😐	😊	😍
5	Means a lot	😢	☹️	😐	😊	😍

After each event, the participants will be provided with a post-exposure survey. The survey instrument includes questions similar to those in the pre-exposure survey. Further questions were added to measure interest in further lessons and attributes such as enjoyment and satisfaction. We also asked the teaching team for their feedback on the effectiveness of the modules.

5. RESULTS

Through the survey instruments, the authors could answer the research questions. The findings are presented according to each research question.

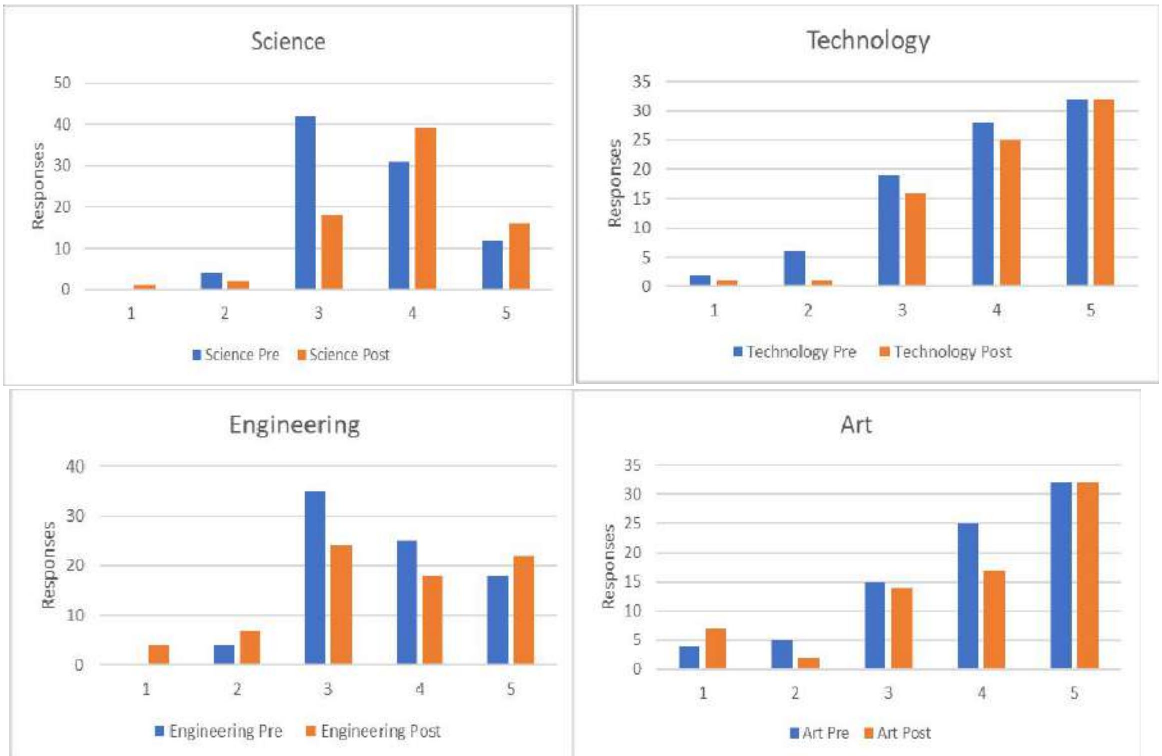
5.1. How effective are the modules at engaging underrepresented minorities in STEAM?

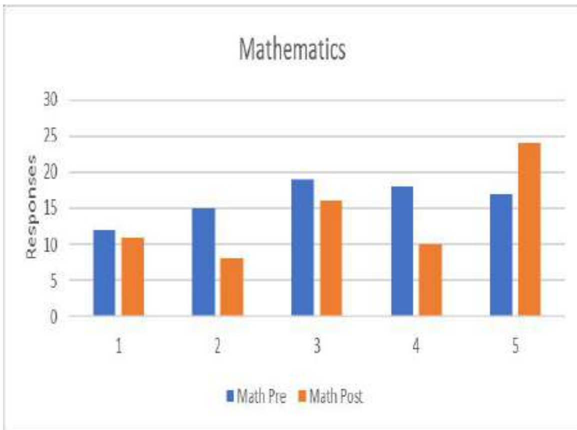
Throughout the sessions, the researchers and the classroom teachers observed high levels of engagement in the modules. The choice of local stories gave the students something they could relate to.

5.2. How much do the modules affect the perceptions and persistence of STEAM?

A significant improvement in the perceptions of specific STEAM subjects can be seen in the frequency of responses.

Figure 2.
Changes in perceptions of STEAM Subjects

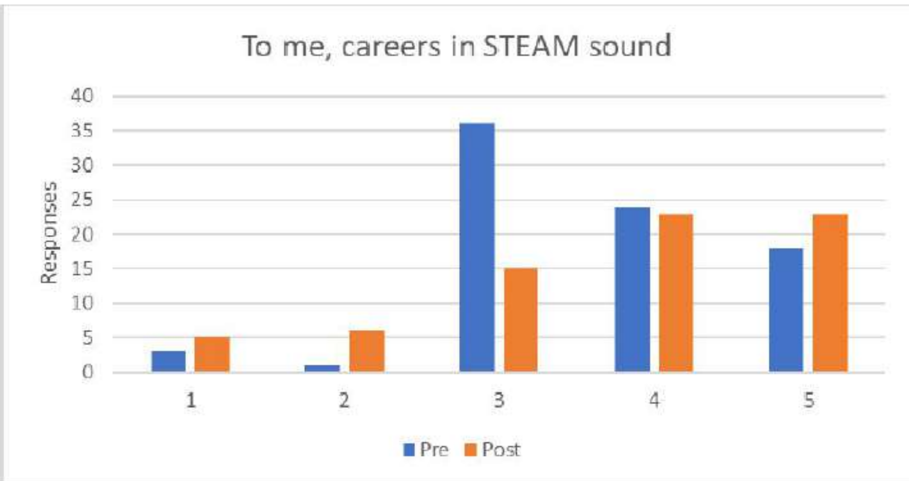




As detailed in Figure 2, the authors found notable changes in perceptions of Science. In the pre- exposure survey, most students indicated that Science was 'Meh' (or average). The results show a 57% reduction in the Meh rating between pre- and post-exposures. Moreover, the responses to the Agree rating improved by 26%, and the Strongly Agree rating improved by 33% (collectively 59%). The authors also observed notable changes in perceptions of Engineering. In the pre- exposure survey, a majority of the students indicated that Engineering was Meh. However, the post-exposure survey shows a significant reduction in the Meh rating (31%). Although the Agree rating did drop by 28%, the Strongly Agree rating improved by 22%. In Mathematics, we observed a slight decrease in the Meh rating (16%) and a significant improvement in the Strongly Argee rating (41%). However, the Agree rating dropped by 44%.

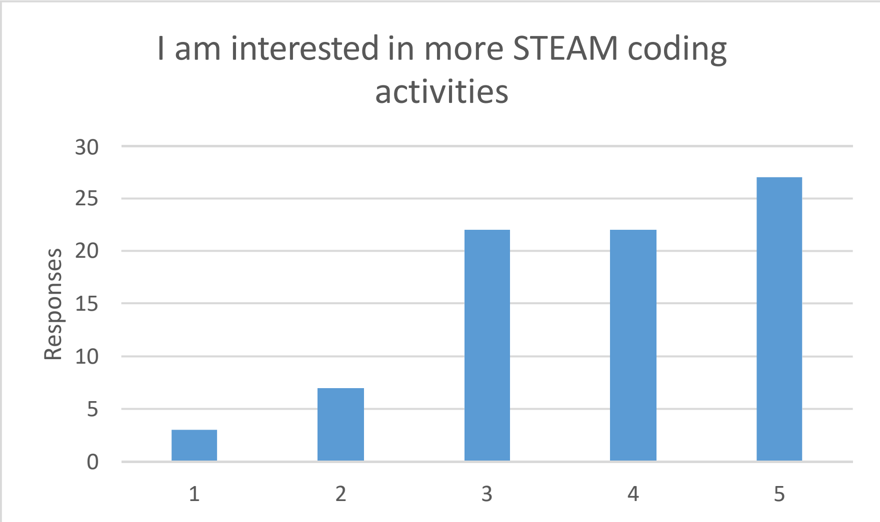
We were surprised to see no real changes in perceptions of Technology. However, the students appeared to have positive attitudes toward technology in general. We also did not observe significant changes in perceptions of Art. We noted that in both Schools, the students were using relatively old Chromebooks, and during the sessions, we observed some latent dissatisfaction with the reliability of these devices.

Figure 3.
Changes in the persistence of STEAM Subjects



To understand any changes in the persistence of STEAM subjects, we asked the students about their perceptions of careers in STEAM. We found a significant reduction in the Meh rating and positive improvements in the Strongly Agree rating (Figure 3). We also asked the students if they wanted additional STEAM coding activities. From the results (Figure 4), we can see a positive trend that the majority of students were interested in more STEAM coding activities.

Figure 4.
Interest in more STEAM Coding activities



5.3. How effective were the modules for the teachers?

We also surveyed the teachers at the sessions' conclusion, and all expressed an interest in getting further resources. The teachers all reported strong student engagement and participation.

6. DISCUSSION

This study focused on using Indigenous stories to engage underrepresented minorities in STEAM. Through engaging with the students in a classroom setting, we evaluated the contribution the modules made to improving participation and perceptions of STEAM subjects. From the results of this study, the authors conclude that this was a positive experience for the teachers and the students. The students were deeply engaged in learning subjects they perceived as hard or boring.

Although this study is limited to two schools in one city, the results are encouraging. We hope to extend the study to a broader population to provide more generalisable results. Furthermore, this study was limited to one school term in one school year. To achieve and evaluate long-term results, a longitudinal project would be beneficial in providing generalisable data.

7. ACKNOWLEDGEMENTS

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Bot-Makers: A Board Game for teaching robot ethics

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Abstract

Robo-ethics is an emerging field in robotics and an important aspect to be considered during robot development. The aim is to stimulate constructive and in-depth discussions around care robo-ethics in the context of care robotics amongst students who play board games. This paper explores the benefits and challenges of using a board game, Bot Makers, to effectively generate stimulating and constructive discussions around robo-ethics among students and the strengths and weaknesses of this endeavour. Results highlighted that the game's strengths were its ability to encourage collaboration between players, provide a safe and comfortable environment, and stimulate constructive on-topic discussions.

Key Words: ethics, robots, board games, education, play

1. INTRODUCTION

Robo-ethics, specifically care robo-ethics, is an emerging field in robotics and an important aspect to be considered during robot development. To ensure that robo-ethics is considered adequately during development, it is important to train those in charge of that development. This leads to training robot developers before they enter the workforce, where a misstep can adversely impact the field and wider society. Current training of robotics and software developers in tertiary education involves a more theoretical understanding of ethics, which lacks the practical and more complex nature of decision-making in real-life development processes. The authors developed a discussion-based board game to aid in this more practical understanding of robo-ethics in the real world to incentivise university students to consider and balance the various perspectives encountered during the decision-making process. The aim is to stimulate constructive and in-depth discussion of robo-ethics amongst board game students in the care robotics context. The board game is intended to facilitate this robo-ethics discussion by creating a team-based development environment, where open and honest discussions about various perspectives on different possible scenarios are debated to allow students to consider and think about the wide range of perspectives that they may encounter in their future careers and the sometimes difficult choices they may have to make. This paper is a pilot study on the design and application of a board game to effectively facilitate discussions around care robo-ethics among university students and the strengths and weaknesses of this endeavour.

2. LITERATURE REVIEW

Robo-ethics addresses the moral challenges and implications associated with the burgeoning use of robots and autonomous systems in everyday life. As these entities assume roles from manufacturing to companionship, ethical considerations become increasingly intricate, often transcending conventional moral paradigms (Anderson & Anderson, 2007; Moor, 2006; Hoxha, et al., 2018). Buechner (2018) underscored the urgency of equipping AI with complex moral reasoning capabilities, ensuring they act in ways that are ethically justifiable when autonomous. Wallach & Allen (2009) argued that constructing ethical algorithms could guide AI behaviour, enabling robots to evaluate the ethical dimensions of their actions in real time. The evolving discourse in robo-ethics not only emphasises preventing harm but also contemplates the broader social and moral impact of integrating intelligent agents into the fabric of society, underscoring the need for an adaptive ethical framework as AI technology progresses.

2.1. Robo-ethics in Game-Based Learning

Robo-ethics, a subset of applied ethics dealing with robotics and AI, is particularly well-suited for exploration through game-based learning due to its inherently complex and multifaceted nature. Game-based learning presents a unique platform where real-world ethical dilemmas of robotics and AI can be replicated in an environment that encourages deep thinking and engagement. Lin et al. (2011) emphasised the importance of simulating realistic ethical scenarios that students might face in professional contexts, making ethical theories more relatable and understandable. Winfield & Jirotka (2018) further discussed the role of game-based learning in robo-ethics, noting that it allows for an interactive exploration of the consequences of decisions in a controlled, risk-free setting. By integrating robo-ethics into games, learners can navigate complex ethical landscapes, make decisions, and witness the outcomes of those decisions in a virtual setting. This practical approach helps learners consolidate their theoretical knowledge with practical skills, bridging the gap between abstract ethical concepts and tangible, real-world applications.

2.2. Impact of Game Complexity on Ethical Reasoning

The role of complexity in educational games, particularly those focused on ethical reasoning, cannot be overstated. Briggle et al. (2016) and Pereira et al. (2012) have shown that introducing complex scenarios that demand consideration of a broad spectrum of variables and potential consequences encourages players to engage in a deeper level of ethical reasoning. The complexity of these scenarios should be such that players are required to synthesise information, anticipate consequences, and navigate the murky waters of ethical ambiguity. Engaging in complex decision-making does not merely teach players what and how to think ethically (de Graaf, 2016). The intricacy of ethical decision-making in real life is often about balancing competing values and interests, predicting outcomes, and making the best possible choices in the face of uncertainty. By mirroring this complexity within game scenarios, educational games can become powerful tools for developing ethical reasoning skills crucial for personal development and professional competence in fields where ethical decision-making is paramount.

3. METHODOLOGY

3.1. The intervention

Bot Makers was developed as a robo-ethics board game, as shown in Figure 1, which requires players acting as robot developers to work together and have meaningful discussions to ethically develop a care robot that meets the team's goals. Each player is assigned and is solely responsible for one of the four care robo-ethics topic areas: Privacy, Human-Robot Interaction, Sustainability, and Project Resources. Each player would need to advocate for their area during the development of the care robot. In addition to the team's goals, each player has individual goals they need to achieve to be the "best developer" and win overall. Having both team and individual goals simulates the feelings of cooperation and tension between areas when ethically designing a care robot, where the player must balance conflicting goals and agendas.

Figure 1.
The Bot Makers board game

3.2. The study

The research involved a qualitative study of fourteen undergraduate students at the University of Auckland. The authors used a convenience sampling method (Ethics Protocol UAHPEC24339). The students were either first- or second-year and had prior exposure to playing board games or video games. To answer the research questions, the researchers developed a prototype board game and asked students to provide feedback on the game mechanics and if they felt it engaged them in learning about robot ethics. The students were asked to play the game until completion while the research team observed their interactions. Upon completing the game, the students were provided with a survey instrument. The survey instrument included a series of questions to help the researchers understand the effectiveness of the intervention and get valuable input into how the game could be improved. Using a 5-point Likert scale, the authors sought to obtain qualitative feedback on the pedagogical value of our game and what areas of the game could be improved.

4. RESULTS

Overall, the quantitative results from the post-game questionnaire were categorised into seven main characteristics, as shown in Figure 2.

4.1. Game Characteristics Analysis

4.1.1. Learn-ability

The general consensus among participants was that learning to play Bot Makers was easy, and the game rules were clear. Most participants agreed on this, while a minority were neutral to it. Since the game is designed to be learnt and played within the time confines of a university lecture, Bot Makers was sufficiently simple to meet these demands. However, it should be noted that the presence of two researchers to dictate the rules and invigilate sessions likely decreased the complexity of Bot Makers. Additionally, the game was already set up for participants. An out-of-the-box style game session would likely increase the complexity of Bot Makers.

4.1.2. Enjoyability

Overall, participants found the game motivating and the experience fun. All participants agreed that the game experience was fun, and most thought the game motivated them to keep playing, except for one neutral participant. The weakest aspect of the game engagement characteristic was the story immersion. Less than half of the participants agreed that they felt immersed in the story of Bot Makers, with the majority neutral in this sentiment and one participant in disagreement. Interestingly, players still found the game engaging and fun despite the lack of story immersion. However, it is likely that the lack of story immersion negatively impacted other characteristics of Bot Makers.

4.1.3. Collaborative Environment

The collaborative environment Bot Makers creates is a relatively strong game attribute. Players felt everyone participated in game discussions and that the game created an atmosphere where each member had an equal opportunity to participate. Most students agreed with this sentiment, and a minority opposed it. This is beneficial because, in lecture settings, only the more confident and extroverted students often engage in conversations. Bot Makers allowed every player to contribute equally to discussions naturally. The sentiment regarding whether participants thought their group worked well together was a bit more divisive. The majority of students strongly agreed with this, while two students disagreed. This divisiveness may be due to the nature of the game, which pits personal goals against team goals. In such games, some player types will prioritise the team goal while others will prioritise their personal goal, leading to different degrees of perceived success as a collaboration.

4.1.4. Comfortable Environment

This was the strongest characteristic of the game, with players expressing that they felt comfortable expressing their opinions and socially connected to other players. The questionnaire showed that all participants agreed that they felt a social connection to other players and that they felt no judgment when expressing their thoughts to the group. Players feeling comfortable expressing their opinions is likely a factor that also positively affected the collaborative environment characteristic of Bot Makers mentioned above. The questionnaire prompt,' I felt like myself when playing the game,' was more divisive, with two students disagreeing with this statement. This divisiveness may be because Bot Makers asks players to play a different role based on who they are personally. For example, a player who disagreed with the statement above said that the aspect of the game they liked least was a strange disconnect between what they wanted to do and what they had to do for their role. So, while using different player roles allowed for a judgment-free environment for player discussions, players also felt that it removed some of their individuality and forced them into making certain in-game choices.

Figure. 2.
Quantitative Questionnaire Results

Quantitative Questionnaire Results - Table

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Learning how to play the game was easy to understand	0	0	2	8	4
The rules of the game were clear and easy to remember	0	0	4	5	5
I felt immersed in the story when playing the game	0	1	7	4	2
I felt the game was engaging and motivated me to keep playing	0	0	1	8	5
Overall, the game experience was fun	0	0	0	8	6
I felt our group worked together to achieve the goals of the game	0	2	2	1	9
I felt every group member had equal opportunity to participate in discussions	0	0	2	5	6
I felt every group member participated in discussions	0	0	0	8	5
I felt socially connected to the other members of the group	0	0	0	7	7
I felt like myself when playing the game	0	2	2	4	5
I felt comfortable expressing my honest perspective to others	0	0	1	2	10
I felt no judgement when expressing my perspective to other	0	0	0	3	10
I would play this game again	1	0	1	9	3
Group discussions were heavily prompted by the game	0	0	2	4	7
Group discussions were on-topic	0	0	0	4	9
Group discussion were in-depth on the topic being discussed	1	0	7	4	1
Group discussions were constructive and not hurtful	0	0	0	1	12
Group discussions made me think about how other members of the group have different perspectives from my own	1	3	3	5	1
Overall, discussions were helpful in understanding the ethical dilemmas engineers face, and how different perspectives need to be considered at every stage of development	0	0	1	3	9

4.1.5. Replayability

According to the quantitative data collected on the questionnaire, replayability was the weakest attribute of Bot Makers. While most participants agreed that they would play the game again, one participant strongly disagreed with this statement. A few participants mentioned in the questionnaire that they were unsure about the game's replayability. They felt that after a few games, players would become familiar with the decisions and the outcomes of these decisions. Furthermore, it was also observed that as players grew more accustomed to the decision-making style, choosing the optimal outcome became more straightforward, and the complexity of in-game discussions was reduced.

4.1.6. Discussion Quality

Bot Makers' ability to generate constructive discussions around care robo-ethics was also a relative strength of the game. Almost all participants strongly agreed that in-game discussions were constructive and not hurtful. Additionally, most participants agreed that the game heavily prompted group discussions and that these discussions were based on robo-ethics. The students found that the Bot Makers game environment generated on-topic and constructive discussions around robo-ethics. However, participants disagreed with the sentiment that "group discussions were in-depth on the topic (robo-ethics) being discussed". Less than half of the participants agreed with this, with most agreeing neutrally and one strongly disagreeing. The comments on the questionnaire provide further evidence regarding the lack of depth in the game discussions, with participants claiming that "without experience in roles... discussions can be superficial" and that "(their) decisions throughout the game were more motivated by (their) desire to win... (rather than) making necessarily the most ethical choice". The lack of depth in discussions may be due to the more simplistic nature of the game and the lack of narrative it provides.

4.1.7. Considering Other Perspectives

Participants thought the ability of the game to make them consider other perspectives was the weakest characteristic of Bot Makers. Most participants strongly agreed that Bot Makers helped them understand the ethical dilemmas engineers face when developing a care robot. However, the opinion on whether the game helped them consider the perspective of other group members was more scattered, with less than half agreeing with this. The lack of depth during game discussions could have contributed to this. If discussions tended to be more superficial, players would not need to empathise with other perspectives to make the relatively simplistic decisions the game required. However, there may also be other parts of the game's design that contribute to the relative weakness of this game characteristic.

5. DISCUSSION

Players found the game to be an engaging experience, supported by both quantitative and qualitative data. This is due to the more fun and interactive nature of a board game activity compared to discussions in lectures and tutorials, which can be more mundane. This supports how engaging in a more practical side of ethics can stimulate greater interest in ethics and the importance of ethical development in participants, as seen in the Privacy by Design study (Gibson, & Douglas, 2013). Additionally, the players in the board game are all of similar backgrounds (students), which reduces the power imbalance seen in lectures or tutorials. This can lead to more relaxed conversations which are more honest and in-depth when compared to lectures or tutorials as there may be less pressure to "get the right answer".

Results showed that player sentiment towards collaboration was positive, which suggests that the connection between players and their caring nature towards one another helps to improve the perception of collaboration between people. This creates a more stimulating and positive environment for players to have open and honest conversations about robo-ethics and its implications during decision-making. The lack of a power imbalance and equality would also support greater collaboration. Creating a safe, collaborative environment through a board game allows players to make ethical decisions and experience the consequences of those decisions without fear (Briggle et al., 2016).

Players suggested the need for more moral challenges during decision-making in the game. This could be because of how easy some decision scenarios are compared to others. Players may feel a lack of challenge due to exposure to various decision scenarios in terms of difficulty. Once a player has experienced how challenging a decision scenario can be and the stimulation associated with the discussions of a challenging scenario, getting a decision scenario where the decision is obvious can be underwhelming and unstimulating for players. Stimulating discussions helps to create an engaging experience, so the perception of easy decisions can disengage players from the game, which leads to less stimulating discussions and more disengagement. This is consistent with existing research where the black-and-white nature of ethical decisions that need to be made may not be sufficient to stimulate ethical discussions (Briggle et al., 2016). The difficulty of making decisions in decision scenarios should be kept consistent to avoid this cycle. It can also be graduated so that decision-making is easier at the start of the game and gets progressively harder as the game progresses.

Players also identified wanting more control over the game. This stems from the idea of player agency and the ability of players to control certain outcomes through their actions. One example where player agency is limited is through decision scenarios where decision options are limited to two options. The intent of limited decision options is to ensure the game is understandable and easy to play while also keeping the game moving forward so players don't spend much time discussing all the various options in decision scenarios. On balance, limiting decision scenario options is a good idea as constraints, such as limited time for playing the game, need to be met. Results show that players desire special cards that allow them to perform certain actions within the game. While this is provided in a limited capacity through certain event cards, which can provide the holder of the card with special abilities, these cards are distributed randomly when the player lands on the event square and receives this card. This random distribution makes it harder for all players to have special abilities in the game. The idea of giving all players special abilities in the game should be further explored to give all players greater agency while still meeting the constraints of the game in which this would be played.

Results showed that players have an "I want to win" mentality stemming from the scoring mechanism used in the game. The scoring mechanism, therefore, needs to be modified to reduce this mentality, as the game is not intended to have winners and losers but to educate all players on robo-ethics and its role in the decision-making process. However, it is important to note that other factors may lead to this mentality. Some players may have an "achievers" or "killers" player type (Taspinar, et al., 2016), which encourages them to win, and any modifications to the scoring mechanism would need to consider these player types to ensure the focus is not on winning, but on in-depth discussions on robo-ethics. Players felt that too many events were occurring in the game, which limited opportunities for decision-making and discussion. Players may feel this way as events occur outside the player's/team's control. Events can negatively impact scoring, which some players did not like as they felt there were too many of these negative events. In this game, since the focus is on ethical discussions, the number of events and opportunities to land on the event squares should be reduced to ensure that decision opportunities can present themselves more often.

The feedback from the students was generally positive but also showed a residual of dissatisfaction. Some of the dissatisfaction can be explained from the early stage of development. While acknowledging the limitations imposed by the design and execution of the exploratory study, the measurable changes suggest that a board game to introduce University students provides motivational value. Students used the concepts of games and fun to express satisfying learning experiences in routine lectures and the promise of the benefits of additional development and testing.

6. ACKNOWLEDGEMENTS

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Cultivating Technological and Engineering Thinking: An Exploration of "Problem-Embedded" Practical Teaching

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Abstract

This paper explores the implementation of “problem-embedded” practical teaching in the general technology curriculum to cultivate technological and engineering thinking. By embedding tasks within real-world contexts, students engage in activities that develop critical thinking and problem-solving skills. The approach focuses on three strategies: guiding students to think like technology experts, conducting practice in authentic settings, and using essential problems for learning scaffolding. The study outlines key teaching processes such as context exploration, solution design, and model making, demonstrating how this method effectively bridges theory and practice, and offers innovative strategies for educational advancement.

Key Words : technological and engineering thinking, Problem-Embedded, Practical Teaching

With the rapid development of society, technological and engineering thinking has become an indispensable part of modern education. Students not only need to master basic knowledge but also must develop the ability to solve complex problems. Therefore, cultivating students' technological and engineering thinking is crucial. In the general technology curriculum, how to effectively cultivate students' technological and engineering thinking and practical skills has become a pressing issue for educators.

1. CORE CONTENT OF TECHNOLOGICAL AND ENGINEERING THINKING IN THE GENERAL TECHNOLOGY CURRICULUM

The general technology curriculum involves technological thinking, engineering thinking, and design thinking. Technological thinking focuses on how to use technological tools and methods to solve practical problems. Engineering thinking primarily focuses on designing and implementing solutions to complex problems, emphasizing systematization, feasibility, and efficiency(MOE，2020）. Design thinking is a human-centered innovation approach aimed at creating valuable solutions by understanding user needs（D.shool,2017）. (see Table 1).

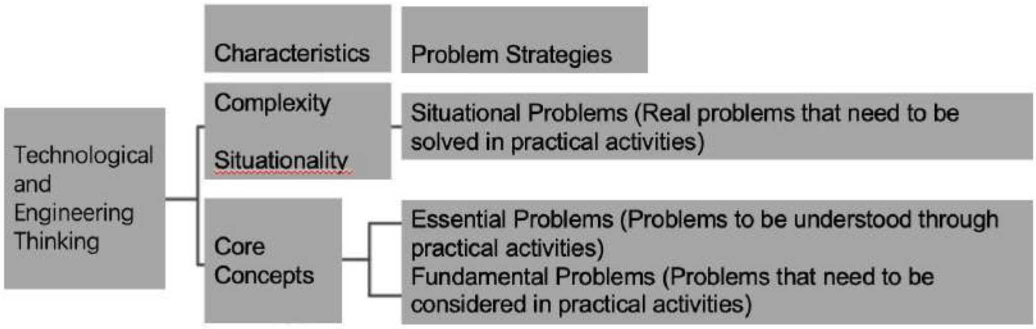
Table 1.
Core Content of Technological and Engineering Thinking in the General Technology Curriculum

Technical Thinking:	Engineering Thinking:	Design Thinking:
- Function	- System	- User
- Performance	- Constraints	- Empathy
- Standard	- Risk	- Needs
- Model	- Cost	- Alternatives
- Technology	- Decision	- Iteration
- Process	- Modeling	- Effective Failure
- Experiment	- Evaluation	

2. ADVOCACY OF "PROBLEM-EMBEDDED" PRACTICAL TEACHING

To effectively cultivate students' technological and engineering thinking, "Problem-Embedded" practical teaching has been proposed. This approach uses task-driven methods to engage students in design, production, and experimentation activities around real-world problems. Through thinking about fundamental issues based on the core concepts of the discipline during practice, students not only improve their practical skills but also learn to think and solve problems like technological and engineering experts (see Figure 1).

Figure1.
Characteristics of technological and engineering thinking and Problem Strategies



"Problem-Embedded" practical teaching emphasizes guiding students to learn and apply technological and engineering thinking through real-world problem situations. This teaching method is based on the following three propositions:

1.1. Cultivate Students to Think and Solve Problems Like Technology Experts

Cultivating students' technical and engineering thinking is not about training them to become experts in the field, but rather about helping them adopt and learn the ways experts think about problems. This involves developing higher-order thinking skills such as system thinking, decision-making, and iteration, which are characteristic of technical and engineering experts. Additionally, it involves analyzing the problems that novice students encounter in technical learning from the perspective of expert thinking, in order to propose appropriate teaching strategies.

1.2. Engage in Technological Practice Activities in Real Contexts

Through authentic contextual settings, students can apply learned knowledge to complex problems, exercising their ability to solve real-world issues.

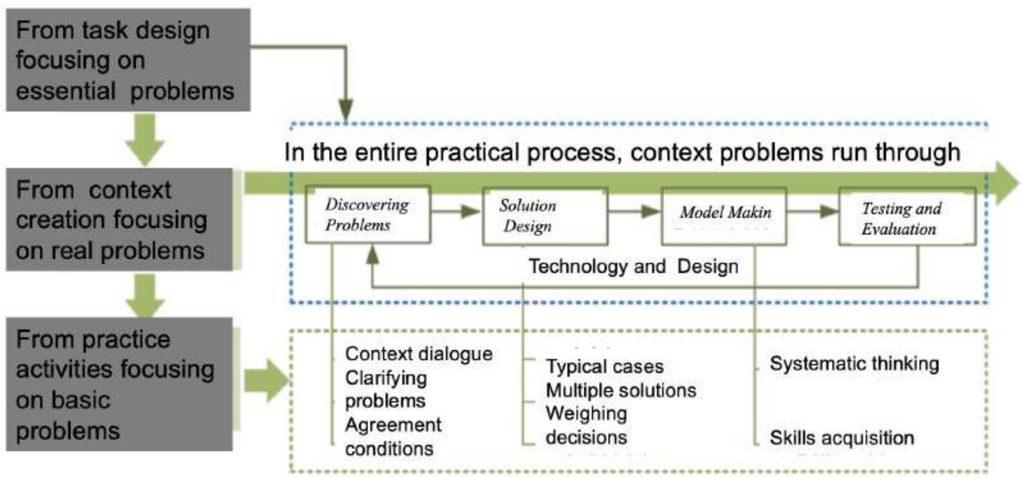
1.3. Lead with Essential Problems and Scaffold with Basic Problems

Experts think about problems in their field through core concepts and ideas. "Problem-embedded" practice teaching guides students' thinking through essential questions and scaffolds them with basic questions. Essential questions are designed by teachers to reflect key inquiries of the discipline and point to core concepts; they are the underlying questions behind students' practical activities. Basic questions, on the other hand, are those that arise during practical activities, prompting students to connect with their practical experiences and continuously think about core concepts.

3. BASIC MODEL OF "PROBLEM-EMBEDDED" PRACTICAL TEACHING

The "Problem-Embedded" practical teaching model combines project-based learning, task-driven methods, and problem-based learning, addressing the inadequacies of these methods in developing thinking skills (see Figure 2). This model aims to enhance students' thinking abilities and practical skills through a comprehensive application of various teaching methods.

Figure 2.
Basic Model of "Problem-Embedded" Practical Teaching



3.1. Process of Problem-Embedded Practical Teaching

3.1.1. Essential Problem as the First Step in Task Design
"Problem-Embedded" practical teaching emphasizes identifying essential problems first, then leading task design with these problems. Determining essential problems requires analyzing, summarizing, and refining core concepts based on curriculum standards.

3.1.2. Real Problems as the Basis for Context Creation
"Problem-Embedded" practical teaching emphasizes embedding context throughout the learning process. The context provides a background or scene, including the problem to be solved and its constraints, guiding the task's proposal and the knowledge and skills to be applied. In the general technology curriculum, technology and design often use product design as a vehicle, forming the context in practice through three steps: constructing typical user roles, describing behavior activities, and refining user needs.

3.1.3. Basic Problems as the Driving Force of Practical Activities
Basic problems are linked to core concepts and practical activities. Through basic problems, students are encouraged to think deeply about core concepts in practice, promoting deep learning and avoiding superficial practice activities.

3.2. Operational Points of Problem-Embedded Practical Teaching

Years of teaching experiments and research have led to the following operational points, guiding the effective implementation of practical teaching:

3.2.1. Context Exploration
Conducting practice based on context is one of the challenges students face in solving complex problems. The method to address this challenge is context exploration, which manifests in students' practical behaviors and cognitive activities, including context dialogue, problem clarification, and constraint clarification.

- Experience 1a: Conduct context dialogues to help students recognize the value of context. Guide students to use empathy to analyze and understand user roles and behaviors, comprehending the worldview and values within the context.

- Experience 1b: Help students clarify problems. Problems in context are often vague and uncertain, requiring further clarification of the background, causes, and key issues to be addressed.

- Experience 1c: Help students clarify constraints. A feature of expert thinking is designing within constraints. Therefore, students need to understand what constraints affect problem-solving, such as the product's use environment, cost, user characteristics, and whether the designer has the necessary technical skills and conditions.

3.2.2. Solution Design
The process of conceptualizing solutions is one of innovation. The distinction between "routine design" and "fundamental design" from a design perspective differentiates between design and invention activities in the general technology curriculum(Vincenti,1990). Routine design innovatively solves problems based on context, while fundamental design is original, involving invention and creation. This distinction helps teachers move away from selecting tasks and guiding design from an invention perspective, focusing more on applying cognitive strategies in routine design tasks and cultivating expert thinking.

- Experience 2a: Help students fully utilize precedents. Experts effectively use precedents, but novices often design intuitively(Lawson,2004). Teachers should guide students in collecting information and systematically analyzing the interaction between people, products, and environments, such as considering the main functions of a product and the sub-functions of its components. Analyzing precedents helps explain expert thinking, such as the challenges experts face, how they make decisions, and how they ultimately solve problems.

- Experience 2b: Encourage students to design multiple solutions. Experts typically use breadth-first and top-down strategies, while novices often use depth-first methods to solve problems. Breadth-first emphasizes an overall grasp and multiple solution conception, while depth-first involves exploring parts to refine solutions(Cross,2010). Therefore, teaching should guide students to change strategies and design multiple solutions. The key to multiple solutions is getting students to think about whether the designed solutions have fundamental differences or merely superficial ones.

- Experience 2c: Guide students to collaborate and make decisions through comparison and weighing. Experts make decisions among alternative solutions through comparison and weighing. After generating multiple solutions, these solutions are often compared and weighed against each other. Guide students to think about the advantages, limitations, and unique aspects of these solutions. Encourage students to listen and negotiate in collaboration, reflecting on "whether I carefully considered my peers' solutions" and "what suggestions from others are worth referencing."

3.2.3. Model Making

Model making is a crucial step in cultivating students' practical skills. Models and drawings are the language of technology and design, tools for thinking. The model-making process reflects design thinking and develops the creative process of conceptualization. Through model making and technical testing, students verify the feasibility of solutions and the rationality of applying knowledge and skills, laying the foundation for technological iteration.

- Experience 3a: Guide students in systematic thinking during hands-on practice. Technology and design practice is a complex process involving materials, tools, processes, time, labor, and other factors. Guide students to have a holistic view and a perspective of connections in hands-on practice, allowing them to grasp the overall picture and think about problems from various angles. For example, when choosing materials, consider their technical properties: what are their strength and hardness? How can they be formed, connected, and surface-treated? How do materials affect the structure? Guide students to adjust designs by considering whether current actions align with initial plans, the next steps, available time, and time needed to complete tasks.

- Experience 3b: Guide students to acquire skills through context-based practice. The key difference between experts and novices in skills lies in their response to contexts. Experts can make fine distinctions in contexts and develop plans from an expert perspective for different contexts. Therefore, guide students to apply skills in specific contexts, identify meaningful elements within contexts, and gain experience in handling real situations. For example, students often lack an understanding of material properties. If materials crack when nails are hammered in, guide students to think about why this happens, whether other processing methods can be used, or if material changes are needed.

"Problem-Embedded" practical teaching, by embedding problems in real contexts, helps students cultivate technological and engineering thinking while solving real-world problems. Through task-driven, context exploration, and solution design, students not only master technological knowledge but also enhance their practical skills and innovative thinking. This teaching exploration provides an effective path for cultivating talents with technological and engineering thinking, offering new ideas for educational reform and development.

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Analysis of Inquiry Tendency in General Technology Subject Textbook for Chinese High School by Romey's Method

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Abstract

The purpose of this paper is to analyze the 2017 edition of China's senior high school general technology subject textbooks (technology and design) which were put together in compliance with the national curriculum standards. The Romey's method, one of the quantitative analysis methods, is employed in this paper to examine 5 types of general technology textbooks in China. By Romey technique, text(T), figures/diagrams(FD), activities(A), and questions(Q) were analyzed in general technology textbooks. As a result of the paper, the values of T analysis, FD analysis, A analysis and Q analysis, which are the Romey evaluation index of the 5 types of general technology textbooks were calculated respectively. The inquiry tendency of textbooks were judged from 4 Romey evaluation indexes. 3 of the 5 types of general technology textbooks in China were inquiry textbooks, and 2 types of textbooks were authoritative textbooks. Through this research, it can assist Chinese high school teachers of general technology subjects in adapting their teaching strategies in the classroom, and aid Chinese high school or general technology teachers in selecting textbooks for future use. In addition, it is also helpful for the compilation and improvement of the high school general technology textbooks in the future.

Key Words: Romey Technique, Technology Textbook, Inquiry Tendency, Evaluation Index

1. INTRODUCTION

As the 21st century unfolds, China has rapidly ascended to the status of a G2 country on the global stage and has achieved significant advancements in various high-tech domains such as aerospace, artificial intelligence and robotics. According to a report by the Australian Strategic Policy Institute (ASPI) titled "ASPI's Critical Technology Tracker: The Global Race for Future Power" (Australian Strategic Policy Institute, March 2, 2023), China emerged as the leader in 37 out of 44 critical future technologies. In light of the intensifying global competition for technological supremacy in the context of the fourth industrial revolution, technology is assuming an increasingly pivotal role. Given that technology education is fundamentally concerned with cultivating competence and literacy in this domain, it becomes pertinent to scrutinize technology education practices within China.

Technology education generally refers to the technology subject education in primary and secondary schools, which is regarded as general education and distinguished from professional technology, and aims to cultivate the technological literacy and competence of primary and secondary school students. Now, China's technology education in the six years of primary school and the three years of junior high school is mainly included in the education of the compulsory subjects "labor" and "science"(Ministry of Education, 2022a; 2022b), in the three years of high school, it is carried out through the independent compulsory subject "general technology"(Ministry of Education, 2020a). Among them, "General Technology" is a subject that pays great attention to the direct experience of students and advocates diverse learning methods such as inquiry and cooperation(Ministry of Education, 2020a). Therefore, the inquiry tendency can be used as an important indicator to evaluate the quality of technology courses in Chinese high schools. In other words, from the aspect of grasping the quality of technology education in Chinese high schools, analyzing the inquiry tendency of its technology education is necessary and meaningful.

So, specifically, how to grasp the inquiry tendency of the technology courses in Chinese high schools? By using Romey's method to analyze the inquiry tendency of technology textbooks in Chinese high schools, it can make it possible. Romey's method(William D. Romey, 1968) is a quantitative method for the study of textbooks, which is currently effectively used in multiple fields such as science, society, sports, and technology. It is a method to numerically transform the inquiry tendency of textbooks, and to objectively analyze and draw conclusions. If the technology curriculum standards are the official documents containing the core content of technology education (what to teach and how to teach in schools), then the technology textbooks can be regarded as the materials to concretize the technology curriculum standards. Especially in China within the national education curriculum system, textbooks are highly important. Up to now, there are a total of five national-level general high school technology textbooks in China, which can be divided according to different publishers into Jiangsu Phoenix Education Press, Henan Science and Technology Press, Guangdong Science and Technology Press, Geological Press, and People's Education Press(Ministry of Education, 2023).

Therefore, the purpose of this paper is to use the Romey's method to analyze the inquiry tendency of the five national technology textbooks in Chinese high schools. In order to achieve this purpose, the specific research questions are as follows: First, what are the evaluation indices of the text, figures/diagrams, activities, and questions in the main text of the textbook based on the Romey's method? Second, how to determine the inquiry tendency of the textbook from the evaluation indices? Third, how about the discussion points of the research results?

2. THEORETICAL BACKGROUND

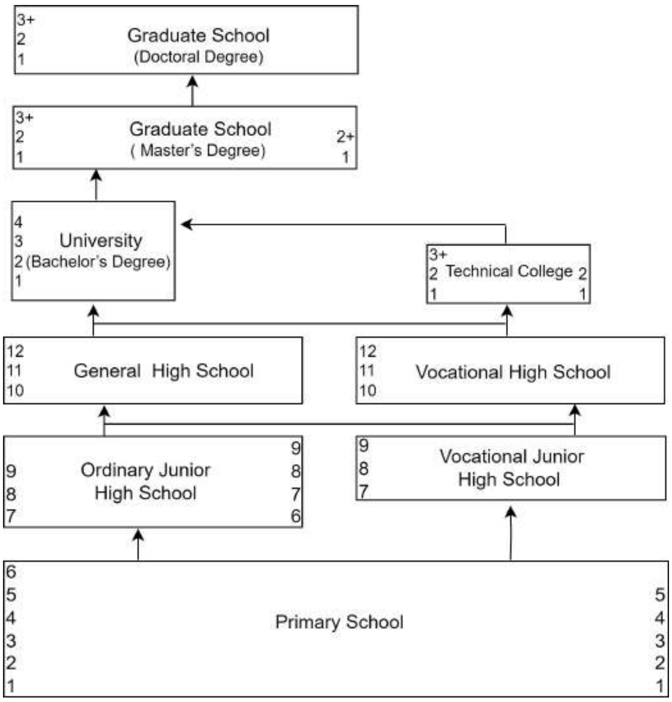
2.1. The educational system in China and the subject setting in general high school in China

2.1.1. The educational system in China

China's compulsory education is a nine-year system (Compulsory Education Law of the People's Republic of China), with either 5 years of primary school and 4 years of junior high school (5-4 system) or 6 years of primary school and 3 years of junior high school (6-3 system). However, currently, in these two types of compulsory education systems, the basic system in China is the 6-3 system. Based on this, in China, children must go to primary school compulsorily when they are 6 to 7 years old, and children can go to junior high school when they are 12 to 13 years old. There are also three-year vocational junior high school in China, but due to the unification of compulsory education, these schools have become practically non-existent. According to the "Statistical Bulletin on the Development of National Education in 2022" issued by the Ministry of Education, currently, there are only 8 vocational junior high schools left in the Chinese mainland, which are used for special education and other purposes (Ministry of Education, July 05, 2022).

The system of general high schools in China is three years, and one can enter school when they are 15 to 16 years old. After graduating from junior high school, in addition to entering general high schools, one can also enter vocational high schools (three-year system), etc. to complete secondary education. China's higher education consists of two to three-year technical colleges, four-year universities (some medical colleges are seven or eight-year systems), two to three-year master's graduate students, and three to four-year doctoral graduate students (Article 17 of Chapter II of the Higher Education Law of the People's Republic of China). The educational system in China is presented in Figure 1. This paper has carried out research on the technology textbooks in general high schools of China.

Figure 1.
Educational System in China



2.1.2. The subject setting in general high school in China

China's Ministry of Education issued the newly revised "General High School Curriculum Program and Curriculum Standards for Each Subject such as Chinese (Edition 2017 Revised in 2020)" on May 11, 2020, further optimizing the curriculum structure(Ministry of Education, May 11, 2020). Table 1 presents the latest subjects and credit settings of general high schools in China(Ministry of Education, 2020b, pp.5-6). The subjects offered in general high schools in China include Chinese, mathematics, foreign languages, ideological and political, history, geography, physics, chemistry, biology, technology (including information technology and general technology), art (or music, fine arts), physical education and health, comprehensive practical activities, and labor. Among them, the technology subject in Chinese high schools includes two separate subjects, namely information technology and general technology, and each of their required contents accounts for 3 credits. Since this paper is to analyze the five types of national textbooks of the general technology subject, in order to facilitate the research, the "general technology subject" is presented as "technology subject", and the "general technology textbooks" is presented as the " technology textbooks".

Table 1.
The setting of offered subjects and credits of general high schools in China

Course	Compulsory Credit	Selectively Compulsory Credit	Elective Credit
Chinese	8	0~6	0~6
mathematics	6	0~6	0~6
foreign languages	6	0~8	0~6
ideological and political	6	0~6	0~4
history	4	0~6	0~4
geography	4	0~6	0~4
physics	6	0~6	0~4
chemistry	4	0~6	0~4
biology	4	0~6	0~4
Technology (including information technology and general technology)	6	0~18	0~4
art (or music, fine arts)	6	0~18	0~4
physical education and health	12	0~18	0~4
comprehensive practical activities	8		
labor	6		
total	88	≧42	≧14

Source: Ministry of Education, 2020b, pp.5-6.

2.2. Types of technology textbooks in general high schools in China

At present, there are a total of five kinds of national technology textbooks being used in general high schools in China, which can be divided into five versions according to the different publishers, namely Jiangsu Phoenix Education Press, Henan Science and Technology Press, Guangdong Science and Technology Press, Geological Press, and People's Education Press(Ministry of Education, 2023). The main editor of every kind of technology textbook and the titles of the textbook are organized as presented in Table 2. From this, it can be known that the five kinds of national technology textbooks for general high schools in China are all composed of two compulsory module textbooks and eleven selectively compulsory module textbooks. In other words, there are no national textbooks for the technology elective modules in general high schools in China.

Table 2.
Types of technology textbooks in general high schools in China

Main Editor	Press	The Title of the Textbook: Compulsory	The Title of the Textbook: Selectively Compulsory
Jianjun Gu	Jiangsu Phoenix Education Press	(1) technology and design 1 (2) technology and design 2	(1) modern home economics technology (2) clothing and the design (3) smart home application design (4) basic engineering design (5) electronic control technology (6) robot design and production (7) technology and career exploration (8) basic vocational technology (9) development of creativity and technological invention (10) 3D design and manufacturing of products (11) special topic on the integrated innovation of science, technology and humanities
Shuigen Fu	Henan Science and Technology Press		
Qiongfa Liu	Guangdong Science and Technology Press		
Lingling Chen	Geological Press		
Junhao Chu	People's Education Press		

Adapted from Ministry of Education, 2023

2.3. The textbook analysis method of Romey

William D. Romey (1968) in his book "Inquiring Teaching Science" put forward six kinds analysis methods to numerically turn the characteristics of the textbook and make objective descriptions. The analysis results can serve as a reference standard for teachers to select textbooks. The six types of analysis methods are as follows:

(i) Rating the Text
(ii) Rating the Figures and Diagrams in the text
(iii) Rating the Questions at the Ends

(iv) Determining an Activities Index for the book
(v) Rating the Chapter Summaries
(vi) Subjective Evaluation

Because methods (V) and (VI) have some problems in objectivity and appropriateness, most researchers only use the first four analysis methods, namely text analysis rating index(T), figure and diagram analysis(FD), activities index(A), and analysis of question at chapter(Q). In this paper, the above four indexes are respectively denoted as T, FD, A, and Q for the ease of the study. The calculation approaches of the four indicators are as indicated in Table 3.

Table 3.
The calculation approaches of the four indicators in the textbook

Indicator	*Calculation Formula*	*Explanation*
Text(T)	$T = \frac{e+f+g+h}{a+b+c+d}$	*a: Fact* *b: Conclusion* *c: Definition* *d: Instant question and answer* *e: Require students to analyze the data of the materials* *f: Let students draw their own conclusions* *g: Let students perform and analyze the activities* *h: The questions in the textbook that do not directly give the answers*
Figure and Diagram(FD)	$FD = \frac{b}{a}$	*a: For the purpose of accurate description* *b：Require students to use the material data*
Activities(A)	$A = \frac{a}{n}$	*n: Analysis of the number of pages* *a: Number of activities*
Question(Q)	$Q = \frac{c+d}{a+b}$	*a: Can directly find the answers from the textbook* *b: Ask for the definition* *c: Require the application of what has been learned* *d: Require to solve the problem on one's own*

Adapted from William D. Romey,1968, pp.44-47.

2.4. Examination of preceding researches

After investigating the prior research related to "the technology textbooks of general high schools in China", it is found that the research on Chinese textbooks mainly focuses on the comparative study of the knowledge content structure of the compulsory textbooks (technology and design) of different versions. Details are as follows:

Wang(2014) in the master's degree thesis titled "Comparison of Two Versions of Domestic General Technology Textbooks", analyzed and compared the high school general technology textbooks (published by Jiangsu Education Press and Guangdong Science and Technology Press) which were compiled and published based on the "General High School Technology Curriculum Standards (Experimental) in 2003" from the perspective of textbook content and STSL (science, technology, society, and life).

Nie(2016) in the master's degree thesis titled "Analysis and Optimization Research on the Case Composition in High School General Technology Textbooks", analyzed and studied the cases in "Technology and Design 1" and "Technology and Design 2" published by Jiangsu Education Press from four dimensions: time, space, purpose, and presentation method.

Liang(2019) in the academic journal paper titled "Revision Contents and Usage Suggestions of the 2019 Edition General High School General Technology (Su Jiao Edition) Textbook", sorted out and analyzed the new changes and main features of the textbook, and put forward usage suggestions from aspects such as material selection, task organization, and teaching evaluation.

Chen(2022) in the master's degree thesis titled "Analysis of Four Versions of High School General Technology Textbooks from the Perspective of STEAM", analyzed the content structure of the high school general technology textbooks of the 2017 edition, and explored the combination of these textbooks with the STEAM education concept.

Deng(2023) in the master's degree thesis titled "Comparative Study of the Compulsory Modules of High School General Technology Textbooks under the Background of the New Curriculum Standards", conducted a comparative analysis of four versions of textbooks except the People's Education Press.

However, this paper is to study the inquiry tendency of the technology textbooks of general high schools in China, and it is different from the above prior research papers. Through this study, not only can it provide information about the actual situation of technology education in general high schools in China, but also the research results can provide a reference for the selection of textbooks for Chinese high school technology subject teachers.

3. METHODS

3.1. Objects of study

As shown in Table 2 in the previous text, there are a total of 5 types of national technology textbooks in China, and each type of textbook has 13 copies. The textbook of "Technology and Design 2" is selected as the analytical object of this paper. The reason is that the large units of the 5 types of "Technology and Design 2" textbooks are all composed of structure and its design, process and its design, system and its design, control and its design.

Also, because the analytical method proposed by Romey requires to randomly select more than 10 pages from the main text of the textbook for analysis, considering the number of pages in each unit, therefore, "structure and its design" is finally selected as a more detailed analytical object.

For the convenience of the research, the textbook published by Jiangsu Phoenix Education Press is marked as A, the textbook published by Henan Science and Technology Press is marked as B, the textbook published by Guangdong Science and Technology Press is marked as C, the textbook published by Geological Press is marked as D, and the textbook published by People's Education Press is marked as E. Twenty-eight pages of the textbooks A and E were analyzed, thirty-nine pages of the textbooks B and D were analyzed, and forty-two pages of the textbook C were analyzed. The specific information about the textbooks of the analytical objects can be seen in Table 4.

Table 4.
The textbooks as the objects of analysis

Textbook	Press	Publication Year	Mark	The large unit name (page number)
technology and design 2	Jiangsu Phoenix Education Press	2019	A	structure and its design (28)
	Henan Science and Technology Press	"	B	structure and its design (39)
	Guangdong Science and Technology Press	"	C	structure and its design (42)
	Geological Press	"	D	structure and its design (39)
	People's Education Press	2020	E	structure and its design (28)

3.2. The approach to the analysis and determination of the inquiry property of the textbook

Based on Romey's textbook analysis methods and theories, use the calculation formula mentioned in the previous text Table 3 to separately calculate the T, FD, A, and Q indices of each version of the textbook. In order to ensure the propriety in the frequency analysis, it was inspected by two high school technology teachers. Then, the determining methods in Table 5 were used to make determinations respectively on the inquiry tendency of the technology textbooks for general high schools in China.

Table 5.
The approach to determining the inquiry tendency in the textbook.

Evaluation Index Value	Interpretation of the Evaluation Index	Inquiry Tendency
evaluation index ＝0	Completely do not require the participation and activities of students.	Non-inquisitive textbook
0<evaluation index≤0.4	Some requirements for students' participation and activities.	"
0.4<evaluation index ≦1.5	Provide students with opportunities to participate in learning.	inquisitive textbook
1.5<evaluation index	The inquiry tendency is too strong, while the learning materials are insufficient	"

Adapted from William D. Romey,1968, pp.47-48.

4. RESULTS

4.1. The analysis result of the text

According to the standards in Table 5, it can be seen that the T values of A and C are both in the interval of greater than 0.4 and less than or equal to 1.5, so they can be said to be inquisitive textbooks, while the T values of B, D, and E are all in the interval of greater than 0 and less than or equal to 0.4, so they are judged to be non-inquisitive textbooks.

Table 6.
The calculation result of the Romey index T

		a+b+c+d	e+f+g+h	T
text analysis rating index (T)	A	91	86	0.945
	B	101	38	0.376
	C	113	78	0.690
	D	115	44	0.386
	E	81	23	0.284

4.2. The analysis result of the figure and diagram

The analysis result of the Romey index FD is shown in Table 7. According to the standards in Table 5, it can be seen that A, B, C, D and E are all non-inquisitive textbooks. It can be said that the figure and diagram of Chinese technology textbooks pay more attention to the role of explanation.

Table 7.
The calculation result of the Romey index FD

	Textbook	a	b	FD
figure and diagram analysis (FD)	A	75	6	0.080
	B	62	5	0.081
	C	94	11	0.117
	D	67	6	0.090
	E	49	5	0.102

4.3. The analysis result of the activities

The analysis result of the Romey index A is shown in Table 8. According to the standards in Table 5, it can be seen that A, B, C, D and E are all inquisitive textbooks.

Table 8.
The calculation result of the Romey index A

	Textbook	n	a	A
activities index (A)	A	28	38	1.357
	B	39	20	0.513
	C	42	32	0.762
	D	39	28	0.718
	E	28	20	0.714

4.4. The analysis result of the question

The analysis result of the Romey index Q is shown in Table . According to the standards in Table 5, it can be seen that A, C and E are inquisitive textbooks, while B and D are non-inquisitive textbooks.

Table 9.
The calculation result of the Romey index Q

	Textbook	a+b	c+d	Q
analysis of question at chapter (Q)	A	2	3	1.500
	B	0	0	0.000
	C	6	7	1.167
	D	0	0	0.000
	E	1	3	3.000

4.5. DISCUSSION

The comprehensive analysis results of the Romey index T, FD, A, and Q of the five versions of technology textbooks in China are shown in Table 10. Comprehensively speaking, A, C, and E can be judged as inquisitive textbooks, while B and D are non-inquisitive textbooks. The fundamental reason why A, C, and E are judged as inquisitive textbooks is that they all provide students with a large number of activities and post-chapter questions. And the fundamental reason why B and D textbooks are judged as non-inquisitive textbooks is the lack of post-chapter questions.

Table 10.
The judgment of the inquiry tendency of the textbook

Textbook	Romey Index	Average Value	Inquiry Tendency

	T	FD	A	Q		
A	0.945	0.080	1.357	1.500	0.971	inquisitive textbook
B	0.376	0.081	0.513	0.000	0.243	Non-inquisitive textbook
C	0.690	0.117	0.762	1.167	0.684	inquisitive textbook
D	0.386	0.090	0.718	0.000	0.299	Non-inquisitive textbook
E	0.284	0.102	0.714	3.000	1.025	inquisitive textbook

5. CONCLUSIONS AND PROPOSALS

At present, there are a total of 5 editions of national general technology textbooks (compulsory course textbooks and selective compulsory course textbooks) used in Chinese high schools, and each edition has 13 volumes. The "Technology and Design 2" textbooks of the 5 editions were selected for analysis. And its large unit of "Structure and Its Design" was selected as the analysis unit.This paper uses the Romey' method to analyze the inquiry tendency of five kinds of technology textbooks in Chinese general high schools. The following conclusions are drawn: First, the Romey's method is proved to be able to quantitatively analyze the inquiry tendency of Chinese technology textbooks. Second, the analysis result of the Romey index shows that A, C, and E are inquisitive textbooks, while B and D are non-inquisitive textbooks.

Based on the above conclusions, the following proposals are made: Among the four Romey indices of textbooks A, C, and E, it is necessary to add some inquisitive elements in the FD part that shows the lowest value when developing new textbooks in the future. And for textbooks B and D, it is necessary to add some diverse questions after the chapters compared to the activities. In addition, although textbooks A and E are judged as inquisitive textbooks, the post-chapter question part overly emphasizes students' inquiry, resulting in difficulty. Some questions that students can directly find the answers from the textbooks should be added.

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The causal relationship between Spatial Ability and performance in Technological Education: A methodological approach

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Abstract

Over the past four decades, spatial ability—especially visualization—has been consistently linked to success in science, technology, engineering, and mathematics (STEM) education. Numerous studies demonstrate that spatial ability significantly influences performance in technological education, with evidence supporting its improvement through targeted interventions, resulting in better academic outcomes and reduced attrition. Although various theories suggest that the spatial nature of activities in technological education underpins this relationship, it remains unclear why spatial ability is critical and which specific aspects of the technology classroom benefit the most.

Technology education, with its broad and task-dependent knowledge base, is uniquely positioned to explore where spatial ability is most crucial. Recent research by Hyland et al. (2023) emphasises spatial ability's role in predicting short-term retention of declarative knowledge in technological and engineering education. However, despite the wealth of research connecting spatial ability to STEM success, a gap remains in understanding how it specifically enhances learning in technology education. This study aims to address this gap by investigating how technology teachers perceive and incorporate spatial ability into their educational practices. Using a surrogate approach that links talent and success as proxies for performance, semi-structured interviews were conducted with practicing technology teachers.

This paper explains the motivation for the study and the methodological decisions undertaken. The current stage of research is focused on analysing the data, with the aim of gaining deeper insights into the relationship between spatial ability and performance in technological education. The findings are expected to provide valuable contributions to both educational practices and future research on spatial ability in technology education and STEM fields more broadly.

Key Words: Spatial ability, Talent, Success, Technological education

1. INTRODUCTION

Spatial ability has emerged as a critical cognitive skill for student success in technological education (Buckley et al., 2018; S. Sorby et al., 2013; S. A. Sorby, 2009a). It is malleable and can be enhanced through specific training interventions. Over the years, various spatial training programs have been developed. One notable intervention, developed by Sorby (S. A. Sorby, 2009b; S. A. Sorby & Baartmans, 1996) within the field of engineering education, has demonstrated a positive impact on problem-solving and analytical skills. Recent work by Hyland et al., (2023, 2024) further underscores its importance in predicting short-term retention of declarative knowledge in the fields of technology and engineering education. Their study explored the relationship between spatial ability, specifically visualization, and knowledge retention in technological and engineering education. The research found that students with higher levels of spatial ability performed better in short-term retention of technical information presented in lectures. This was replicated across two additional studies, suggesting that spatial ability is a robust predictor of knowledge retention, which is theorised as central to academic success, especially for novice learners in technological and engineering disciplines. The findings indicate that spatial ability could play a critical role in how information is processed and retained.

Despite decades of research demonstrating a strong link between spatial ability and success in STEM fields (Alias et al., 2002; S. Sorby et al., 2013, 2018) there remains a lack of detailed understanding of the specific mechanisms by which spatial ability influences learning, problem-solving, and performance outcomes in technology education. This gap is particularly significant given the substantial impact that spatial ability interventions have had on student achievement in STEM (S. Sorby et al., 2018). However, its practical application within technological classrooms remains underexplored. Technology education, with its broad, task- and context-dependent knowledge base (Buckley, 2018), is uniquely positioned to reveal where spatial ability is most critical. Bridging this gap could help translate cognitive theories into practical strategies for the classroom.

One limitation of existing studies is their tendency to focus on the broad relationship between spatial ability and overall educational performance, often relying on correlational studies that compare spatial ability scores with end-of-term assessments. These studies rarely investigate specific teaching practices or explore how spatial ability is applied in classroom learning activities.

To address these challenges, further research is needed that employs methodologies linking individual spatial abilities with measurable outcomes indicative of nuanced aspects of classroom activity and practice. Qualitative insights gained from practice can offer an evidence base to begin theorising such linkages. As such aspects of teaching and learning are often deeply unpacked within academic discourse but may not be as prevalent in practice-based conversations, a useful approach is to use terms more familiar to practice as proxies for constructs of interest in conversations between researchers and educational stakeholders. This paper, which is a work in progress, will rationalise the methodology of a currently underway study which is inclusive of the use of proxy terminologies to highlight how these could be used to gain insights specifically into the relationship between spatial ability and activity in technology classrooms.

2. LITERATURE REVIEW

2.1. Spatial Ability

The cognitive ability of interest in this work is spatial ability, which is described as "the ability to generate, retain, and manipulate abstract visual images" (Lohman, 1988). It is well established that spatial ability correlates with STEM performance. This has been shown through substantial longitudinal evidence (Wai et al., 2009).

Spatial ability assessed during adolescence has surfaced as a salient psychological attribute among those adolescents who subsequently go on to achieve advanced educational credentials and occupations in STEM (Wai et al., 2009). Participants in Wai et al.'s (2009) study were a random sample of N ≈ 400,000 American high school students approximately equally distributed across grades 9 – 12 with approximately equal amounts of males and females. They were subsequently followed up with over 50 years later to see their educational attainment. This longitudinal evidence demonstrated that spatial ability plays a critical role in predicting educational and occupational outcomes in the general population as well as among intellectually talented individuals above and beyond verbal and maths abilities.

Spatial ability has specifically been demonstrated as an important factor in engineering and technology education consistently for the last two decades (Buckley, 2018; S. a Sorby, 1999; S. A. Sorby, 2009a). In terms of technology education, it has been found to be associated with performance on geometric problem-solving tasks (Buckley, Seery, & Canty, 2018) and with performance in design (Lin, 2015). Similar findings are more prevalent in engineering education (Alias et al., 2002; Carbonell Carrera et al., 2011; S. A. Sorby, 2009b) and the importance of this correlation in terms of education is apparent through the variety of attempts made to design targeted spatial training interventions (Onyancha et al., 2009; S. Sorby et al., 2013; Stieff & Uttal, 2015).

2.2. Technological Education

Technology education is a crucial context for spatial ability research because many of the tasks and challenges in this field rely heavily on the ability to visualize, manipulate, and understand spatial relationships. Spatial ability plays a central role in the comprehension of technical diagrams, 3D modelling, design processes, and mechanical reasoning – all of which are foundational to success in technology education. Technology education evolved from technical education describes a process in which a skilled practitioner demonstrates mastery of materials and techniques in the production of an object (Gibson, 2019). Having evolved from this, Mitcham (1985) defined technology education in the most general sense as the making and using of artifacts and De Vries (2016) defined it as education concerned with thinking and teaching about technology. Different approaches to technological education have emerged globally, shaped by factors such as perceived economic importance, cultural values, available resources, and heritage, resulting in variations in policy, curriculum, and the definition of technological education. As such, technological education today has many interpretations and variations in practice. Black, (1998) outlines many curricular approaches to technology expanding the work of De Vries (in Jenkins, 1994). These are summarised in Table 1.

Table 1.
Approaches to technological education.

Approach to Technological Education	Description
Concentration on technical skills	Seeking emphasis on craft skills in treating resistant mate- rials, food, and textiles, or in electronics and automatic control.
Concentration on craft	In which the cultural and personal value of the combination of manual skill, aesthetic sensibility, and traditional design is to be preserved.
Concentration on technical production	Seeking emphasis on skills appropriate to modern mass production and its control and organization.
Concentration on engineering apprenticeship	Seeing the school subject as a preparation ground for specialist technicians and engineers in tertiary education.
Concentration on modern technology	Which looks to the nature of "work" in the next century and focuses strongly on information technology.
Concentration on science and technology	In which it is assumed that these two subjects are, or ought to be, studied in close association with each other.

Concentration on design	Seen by some as a central concept in the study and practice of technology.
Concentration on problem-solving	Focusing on an understanding of the nature of social needs in the definition of "problems" and of the need for a cross-disciplinary approach to tackling issues.
Concentration on practical capability	Emphasizing personal and active involvement of pupils in tackling realistic problems to offset the passive and receptive ethos of most of school education.
Concentration on the technology-society nexus	Which calls for study of technological innovation as a driving force for social change and of its interaction with other forces that also drive change.

While there are several variations in approach to technological education, learning through make is a dominant focus. This has stemmed from earlier vocational, handicraft, and apprenticeship education models. In contemporary technological education the focal nature of knowledge is applied, and the nature of activity is inherently interactive. Students explore and try to resolve complex and interrelated technological problems that involve conceptual, procedural, societal, and technical variables (Jones, 1997). Predominantly, the realisation of artefacts is often guided by two distinct approaches – one emphasising technical manufacturing and one emphasising designerly activity and modelling. Technical manufacturing involves creating, reading and interpreting working drawings and the precise making of an artefact, and all associated and dependent activities. The involved learning would centre predominantly around developing knowledge and skills associated with making. Spatial ability is important to making because it enables individuals to visualize and manipulate objects in their mind, understand spatial relationships, and translate conceptual ideas into physical forms, all of which are essential for effectively planning, designing, and constructing artefacts in technology education. This is one reason why technology education is uniquely positioned as a context for studying spatial ability and learning, as it inherently integrates these skills into hands-on, practical activities that require the application of spatial reasoning.

An alternative approach is to emphasise designerly activity, where students are guided to design and produce their own projects, which are typically unique to some degree. With students bringing their ideas from conception to realisation with this approach having a more fluid definition of the technical skills and knowledge that are required, and a heavier emphasis is placed on the decision making essential to resolve their design. Learning in this regard would have an increased emphasis on the capacity to design and making design related decisions. Indeed, in some contexts such as the UK, there is debate about the emphasis which should be given to both approaches within technological education (Barlex, 2019; Spendlove, 2017). The design process can manifest in many ways, such as linear design, cyclical, and iterative. The design process in technological education can be characterised as a goal-directed and iterative activity whereby the designer learns about the problem by proposing solutions and synthesizing ideas (Purzer et al., 2015). Design activity can also be both with or without make, but in technological education there is always a consideration towards make. It can also be described as composed of two basic moments: analysis (breaking down, identifying, and assessing the parts) and synthesis (bringing together or integrating the parts) (Mitcham, 2001), and is an increasing focus of technological education. Specifically, design affords technological education the opportunity to treat problem-solving in context. Researchers have pointed out that a variety of cognitive skills and higher-order thinking skills can be developed and nurtured through application in a practical context (Niiranen, 2021). Further, practical learning and the hands-on nature of technology-related educational activities help students to conceptualize technological knowledge, build practical skills and develop systematic thinking (Gibson, 2019; Ritz & Fan, 2015).

Technological knowledge in education encompasses a broad, task and context-dependent foundation that requires an understanding of various knowledge types. Modern debates continue to explore these knowledge types, particularly the division between Ryle's, 1949 "knowing that" (propositional knowledge) and "knowing how" (skill-based knowledge). Some argue that these knowledge forms overlap, while others maintain their distinction (Hetherington, 2011; Stanley & Willlamson, 2001). This debate is significant in technology education, as technological activities often involve tacit knowledge, which cannot always be explicitly taught (Polanyi, 1969), and provisional knowledge which can be viewed as knowledge whose relevance is based on utility (Kimbell, 2011). The wide variety of relevant knowledge types in the field also position technology education as a useful context for the study of spatial ability in terms of learning due to the central role of knowledge in learning.

In summary, spatial research in technology education is crucial because it directly impacts students' ability to engage with the core activities of the discipline—whether through precise technical manufacturing or creative design processes. A deeper understanding of spatial ability in this context will contribute to more effective teaching methods, better learning outcomes, and the overall advancement of technology education as a field.

3. METHOLOGICAL APPROACH

3.1. Approach

Despite the substantial body of research linking spatial ability to performance in STEM fields, significant gaps remain in our understanding of its specific role within technology education. Much of the existing research has focused on broad correlations between spatial ability and overall STEM performance, often neglecting a detailed examination of how spatial skills are applied in classroom learning activities. Moreover, the majority of studies have centred on end-of-term assessments, offering limited insights into the practical development of spatial ability within technology classrooms.

While quantitative research is essential for providing measurable and statistically significant insights, it may not fully answer the question of how spatial ability contributes to success in technology education. Quantitative methods typically focus on numerical data and correlations, which, while useful for identifying trends, do not capture the nuances of how spatial ability is applied in real classroom settings. This approach often overlooks the rich, contextual details of students' experiences, teaching methods, and the specific ways in which spatial ability manifests during learning activities. Additionally, quantitative studies tend to rely on standardized tests and assessments, which may not fully capture the complex, context-dependent nature of technology education. Furthermore, the quantitative approach can only provide insight into the constructs that are measured—an issue that becomes problematic when it is unclear what exactly should be measured. Therefore, while quantitative research is vital for establishing broad patterns and relationships, it alone may not provide the depth of understanding required to fully explore how spatial ability influences educational outcomes.

To address this gap, several qualitative research methods could be considered for exploring how spatial ability contributes to performance in technology education. Each method offers distinct advantages in capturing the complexity of classroom dynamics and the nuanced role of spatial ability. For instance, interview-based methodologies could facilitate discussions with teachers, allowing for the comparison of different perspectives and experiences. Classroom observations might provide real-time insights into how spatial skills are applied during learning activities. Lastly, document analysis could examine lesson plans and curricula for explicit mentions of spatial skills integration.

While each of these methodologies holds value, interviews are currently viewed as the most appropriate method for advancing the state of knowledge in this area. For example, interviews offer advantages over observations and document analysis when seeking personal insights and interpretations, as they allow participants to share their experiences, thoughts, and reasoning in their own words. Unlike observations, which only capture external behaviours and provide a snapshot of understanding, interviews can delve into the underlying motivations, perceptions, and challenges that teachers face in recognizing and fostering spatial skills. Compared to document analysis, interviews offer real-time, context-rich conversations that can adapt to specific questions and explore abstract concepts in depth, something static documents may not reveal, as policy often does not reflect enacted practice but rather its goals.

3.2. Participants

To investigate the correlation between spatial ability and performance in technological education, gather qualitative incites from stakeholders with relevant experience in this field is considered crucial. Such stakeholders could be policy makers, educators, or learners. Policy makers – such as curriculum developers – can offer useful insights but given the current need to understand spatial ability and its association with learning, their perspectives may be too far removed from student activity in the classroom. In contrast, learners are very well suited to discuss their own engagement in technology classrooms but could lack breadth in their insights and may not be well positioned to reflect on performance as this is tied to learning outcomes, which they may not be aware of. Teachers are considered as the most appropriate stakeholders to address the gap based on the current state of knowledge. Their direct involvement in the classroom positions them to observe, support, and assess students' spatial abilities broadly across several students and several activities. Additionally, teachers have a unique ability to offer insights into how spatial ability influences educational outcomes in practical settings.

To ensure that participants can provide relevant and experienced perspectives, it is considered important that such teachers would have sufficient classroom experience. This criterion therefore excludes early-career teachers – at least temporarily – who may still be developing their teaching identity and classroom efficacy. During the first few years of their careers, teachers often focus on managing classroom demands and refining their teaching practices, which might limit their ability to provide the depth of insight required for this research. By focusing on more experienced teachers, the study aimed to gather rich data and capture a well-rounded understanding of the phenomena under investigation.

3.3. Design

In terms of a method to capture insight from teachers, interview-based approaches can include focus groups and individual interviews. While focus groups offer the advantage of participants provoking thoughts in one another, individual interviews ensure that every participant has an equal opportunity to express their views in depth, without the influence of group dynamics or dominant voices, allowing for a more thorough and personal exploration of each participant's insights. Interviews generally fall into three main categories: structured, semi-Structured, and unstructured. The semi-structured format is considered useful in terms of the aim of gaining insight from practice as this format strikes a balance between providing a framework through guiding questions and allowing enough flexibility for participants to express their thoughts freely. While ensuring that the discussion stayed on topic, this design allowed room for rich, detailed responses.

To improve the validity of the findings and mitigate potential biases, follow-up questions can be used when necessary. These follow-up questions can prompt participants to clarify or expand on their initial responses, fostering a deeper exploration of the subject matter, which is especially important when there is need to gain deep insight and when speaking around a topic of interest. This iterative approach helps to gather more comprehensive insights, ensuring that key themes and nuances were thoroughly understood.

One of the strengths of interviews is their ability to explore sensitive or abstract concepts in a conversational, reflective manner. In this study, discussing the abstract concept of spatial ability posed a challenge as it is not always easily articulated by participants. To address this, the study employed a methodology that used more accessible and familiar terms. Specifically, "talent" and "success" were used as proxies for conversing around spatial ability and performance respectively.

In this context, "talent" refers to an inherent ability to perform certain tasks or activities with ease or proficiency, often without the need for extensive training. By focusing on how participants recognized and supported talent and success, the interviews aimed to uncover their understanding of spatial ability in practice. Using these familiar terms enabled participants to more easily articulate their observations and strategies, leading to richer and more meaningful data collection.

During the interviews participants were be presented with information about spatial ability. This section was not framed as a question but served to ensure that the teachers had a clear understanding of spatial ability before being asked about it directly. This step was essential to make sure the participants could meaningfully engage in the final section of the interview as it was assumed that some teachers might be unfamiliar with the specific concept of spatial ability or its formal definitions, despite potentially encountering it in their teaching practices. Critically, this information was not presented until a broader discussion surrounding talent and success had first taken place. This approach is helpful in avoiding priming the participants about the focal topic, which could skew their answers away from other potentially useful insights.

3.4. Implementation

As noted, this is a currently underway study. To date, semi-structured interviews were carried out over a period of several weeks, following the recruitment of 15 secondary-level technology and engineering teachers. Given the logistical challenges of coordinating in-person interviews, particularly when aiming for geographical diversity among participants, interviews were conducted via video conferencing. This method not only accommodated participants' schedules but also allowed for broader representation without sacrificing the depth and quality of engagement typically associated with face-to-face conversations. The interviews were conducted using Microsoft Teams, with only audio recording to ensure participant comfort and data clarity. Each interview lasted approximately 30 minutes and was structured around five key sections: background information, talent, success, spatial ability information presentation, and a summative reflection. The question were present both audially and visually to the participants to avoid confusion, and allow the teachers understand the question they were been asked.

The interview process was guided by open-ended questions aimed at exploring teachers' perspectives on spatial ability, talent, and success in the context of technology education. These open-ended questions allowed participants to share their insights freely, while also giving the interviewer the flexibility to probe deeper into specific topics when needed. To gain deeper insights while minimizing potential bias, the interviews were structured into two distinct sections. In the first part, teachers were asked to discuss general concepts of "talent" and "success" without directly mentioning spatial ability. As noted, this approach allowed them to speak more freely about how they recognize and nurture various skills in their students, avoiding the influence of preconceived notions relating to spatial ability. This provided an unbiased exploration of teaching practices and student abilities. In the second part of the interview, teachers were then asked more directly about spatial ability and its specific role in their classrooms. This two-part interview structure ensured that initial responses were free from bias, while still allowing for an in-depth discussion on spatial ability during the latter half of the interview. The combination of these approaches helped to produce both broad insights into teaching practices and focused discussions on spatial ability.

4. CONCLUSION

In conclusion, this study will provide a deep exploration of the relationships between talent, success, and spatial ability in the context of technology education. By examining these constructs alongside participants' backgrounds and educational contexts, the study seeks to identify potential causal links and patterns, offering a more nuanced understanding of how spatial ability influences learning outcomes, decision-making, and performance in technology-related subjects.

The research will offer valuable insights into how educators can recognize and nurture talent and success, particularly in fields where spatial reasoning plays a critical role. By gathering firsthand insights from teachers, this study reduces potential biases and enhances our understanding of how spatial ability manifests in educational settings. Additionally, the study examines how spatial ability interacts with knowledge retention in various classroom activities, building on the previous work of Hyland et al., (2023, 2024) and contributing to a deeper theoretical understanding of its role in technological capability.

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Investigating schools as reciprocating sites of Design and Technology Education practice: Lessons from Hyderabad, India

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Abstract

Understanding ongoing STEM education practice is necessary for developing critical reflexivity. This paper reports findings from an exploratory case study investigating the nature and quality of STEM education experience in schools which received a grant-in-aid for establishing and sustaining the Atal Tinkering Laboratories (ATLs) in India. The three schools from the city of Hyderabad, represented a case each and exhibited distinctive characteristics, in terms of their resourcefulness, socioeconomic background of students they cater to, and ways in which they assimilated and enacted STEM education practice through the ATL. The qualitative analysis revealed a varied texture of STEM education in different contextual settings, which seemed to be influenced by school ethos, learning ecology afforded by the ATL environment, curriculum and instructional practices followed, and expectations from a teacher and how s/he exercises their agency. The findings suggest that schools do not operate merely as sites for implementation of a policy directive or an educational initiative. Instead, schools selectively absorb and reciprocate in ways that preserve its vision and long-term sustenance. Understanding and engaging with school's reciprocation will facilitate realising the reflexive and deliberative dimensions of curricular practice and enable refined educational re-envisioning for the 21st Century.

Key Words: Deliberative curriculum, Design & Technology Education, STEM education, learning progression

1. MOTIVATION AND LITERATURE REVIEW

Globally, Science, Technology, Engineering and Mathematics (henceforth, STEM) education has been making massive inroads into curriculum across all education levels, from the early years to higher education. The firm footing gained by STEM education concedes to a society's re-configuration of internalised purposes of education, reformulation of curriculum (Herschbach, 2014) and practice. In the past few decades, epistemic positioning of STEM seems to have evolved from inter-, trans- and multi-disciplinarity (Kayumova, 2019) to beyond. It now strives for a meta-disciplinary identity (Kennedy & Odell, 2023). The evolving epistemology corresponds to change of *teleological* (intrinsically valuable or for its own sake) purpose of education. The role of STEM education in upscaling innovation and economy through problem-solving, entrepreneurship and industry, relates to the *instrumental* purpose of education. Both the purposes of education (Carr, 2003), seems to be undergoing a transformation. Resonating with the global trend, India too has been experiencing a rising interest in STEM education. However, changing Indian educational landscape concomitantly reflects a paradox. In present neoliberal context, the State is withdrawing itself from supporting the public education system. However, it has fervently favoured interface between education, industry and entrepreneurship, which instruments an ecosystem fostering innovation. India represents an evolving society with STEM education simultaneously upholding both the *teleological* and *instrumental* purposes of education. Within this imagination of Indian educational landscape, it would be useful to understand how STEM has been internalized in school functioning, and examine how the promulgated aspects of education policy get translated into practice.

Internationally, the realization of technology education in school curriculum has taken diverse forms and routes depending on the historical subject antecedents (de Vries, 2018) and the socio-political will shaping its curricular incorporation. While diverse approaches to STEM education may be systemic, ingrained in the very character of its imagination, there is much to learn from perspectives and contextual experimentations. An understanding of contextual motives, policy landscape and systematic analysis of curricular initiatives can offer interesting perspectives on the dynamically evolving area of learning engagement. In the past, Indian school curriculum has experimented with inclusion of work education, socially useful productive work, heritage arts and craft, and technical and vocational education. In the present educational regime, STEM education has gained currency. It would be interesting to understand how STEM or Design & Technology education continues to carve its niche within these diverse curricular orientations. Although there have been sporadic efforts in the past towards integrating designing and making in Indian school curriculum, the ATLs represent the first comprehensive and cohesive effort at scale, involving government will and proactive engagement. Moreover, the initiative has had a ripple effect with several private schools reconfiguring school spaces with STEM labs, either with or without the grant-in support.

2. STUDY CONTEXT

The context of curricular reform and practice that constitutes the focus in this paper relates to an educational initiative by Government of India. As part of Atal Innovation Mission (AIM), under the aegis of National Institution for Transforming India (NITI) Aayog (translates to Policy Commission), the government launched the **A**tal **T**inkering **L**aboratories (ATLs) in India with an intent to foster a culture of innovation, self-reliance and entrepreneurship. The ATLs envision "cultivating one million children in India as neoteric innovators" (GoI, 2017, p.3). Consistent with the vision, policies such as the National

Education Policy (NEP) 2020 (GoI, 2020) and National Curriculum Framework on School Education (NCFSE) 2023 (NCERT, 2023) emphasized the need to reimagine curricular and teaching learning spaces to assimilate hands-on learning. ATLs advocate STEM education and use of several 21st Century skills including, curiosity, creativity, imagination, design and computational thinking, adaptive learning, etc. in the curricular modules and teaching practice for students in Grades 6 to 12 (age 11 to 17 years). Schools willing to establish ATLs were invited to submit proposal and seek financial support from the Government. To those schools selected, AIM provided a grant-in-aid covering an establishment cost of one million Indian rupees (or Rupees Ten Lakh) and an operational expense of another one million Indian rupees, for a maximum span of five years. Out of the total grant amount, 12 lakh rupees is disbursed to the school in first year itself whereas the remaining 8 lakhs rupees are disbursed in equal instalments, over a period of four years. The eligibility criteria for schools include, availability of built-up space of 1500 square feet or 1000 square feet for schools from the hilly/Himalayan and island states and the eight union territories, dedicated mathematics and science teachers, basic infrastructure which includes availability of computers and internet connectivity, steady electric connection, science lab, library, playground, and regular attendance of staff and students. Till now, a total of about 10,000 ATLs have been established in the country, of which 110 are located in aspirational districts. There are a total of 112 aspirational districts identified within the 28 states of India, which are recognized as socio-economically poor, which require targeted changes for effective social transformation. A few school hours per week are dedicated in timetable for students to work in ATLs. It is important to critically examine the functional status of ATLs and how STEM education is being realized in different schools, receiving the grant-in-aid, from a policy implementation of this nature and scale.

3. STUDY OBJECTIVES AND RESEARCH QUESTIONS

The study investigates STEM education practices in ATLs in different kinds of schools (government and private) in Hyderabad, through the following research questions.

(i) What differences can be found in practices of ATLs in different kinds of schools?
(ii) What kind of curricular, material, human and social resources are used to capacitate the ATLs in different school settings?
(iii) How do practitioners, from different settings, engage with and reflect on schooling discourses, curricular experiences, and outcomes involving ATL engagements?
(iv) How do learners engage with the ATL modules and their potential in enabling STEM education?

The study sought to understand how prescribed ATL gets contextually realised in various kinds of schools. The research questions aimed to elicit patterns and bring to surface explanations from practice. While the patterns in realising STEM education may emanate from differences in infrastructure, resources and endowments, they could also reflect the socio-political dynamics and pragmatics of school functioning. Closely examining the differences in ATL practices across different schools can provide revealing insights about context, practice and the larger ethos that govern the realisation of STEM education, both from the *emic* and *etic* perspectives. The contextual insights offer opportunities to engage with prospects and challenges associated in realising STEM education through ATLs in diverse Indian schools.

4. METHODOLOGY

This exploratory case study systematically examine the contextual challenges towards meeting policy goal of integrating STEM education in school learning through advancement of ATLs.

4.1. Settings and Sample

In India, depending on the financing, schools are either government-aided or run by private trusts or society. The study sample included a government and two private schools catering to students from different socio-economic class. Three schools were purposively selected based on their willingness to allow access and participation. Each school with its unique compositional attributes of governance and functioning, composition of teachers and learners, board affiliation, and forms of practice, constituted a case. Case selection was guided by criteria as being non-residential, had co-education (both sexes), catering to high school (Grades 6 to 10), following English as the medium of instruction, and close relative proximity with each other. Several private schools applied for ATL in early years of the announcement of the scheme, hence cases of schools Q & R (discussed below) are from those which received the earliest sanction in December 2016. The government schools started applying and receiving grant from March 2018, but a high number of government schools from Hyderabad received grants a year later, in March 2019. The case of school P is drawn from the cluster of schools which received grant in March 2019. All three cases had an established presence of ATL more than three years. These criteria for case selection also offered base characteristics for making relative comparison across cases. Primary data sources included observations of the school, ATL spaces, sample works of learners and conversations with school teachers. All these helped gain an understanding of the STEM engagements and develop case descriptions that bring out contextual nuances.

5. CASE DESCRIPTIONS

Each case was developed through field observations and interactions with teachers on different aspects of schooling and ATL practice. Table 1 refers to a comparative summary of cases.

5.1. School P: Government school

The school was established in 1997, is affiliated to Telangana State board and caters to students from Grades 6 to 10. Each grade has a section each for students following English and Telugu (vernacular language of the State) medium of instruction. The school has a staff room, a room for head teacher, a small library with about 400 books, a room with 2 computers for teaching and learning, a STEM room, 8 classrooms with benches that accommodate 2 to 3 students per bench, and separate toilets for girls and boys. Of the 14 teachers, 4 are male while 10 are female teachers. Several teachers teach students from both the medium of instruction. The school follows the textbooks prescribed by Telangana State Council of Educational Research and Training (TSCERT) and has the public board examinations organised by the State. There are no ramps for making access feasible to differently-abled children. The school does not provide mid-day meal to its students.

5.2. School Q: Private school, catering to middle class

The school was established in 1979, is affiliated to the Central Board of Secondary Education (CBSE) and caters to students from Lower Kindergarten to Grade 12. English is the medium of instruction. Spread over 8 acres of land, the school contains a 3-storey main block, separate primary block, 3 computer labs, sports facilities, canteen, stationery shop and amenities block with a well-equipped library. Separate toilets are available for girls and boys. Various activity-oriented subjects such as drama, music, art and crafts, knitting, embroidery, cookery, oil painting, candle making, yoga, electronics, karate and gymnastics are offered as electives. School has a strength of about 3000 students and 130 teaching and non-teaching staff members. The textbooks prescribed by National Council of Education Research and Training (NCERT) are followed. The school has been a recipient of several awards. It has a global footprint and has a student exchange programme with Japan, Australia, Singapore and the UK.

5.3. School R: Private school, catering to affluent class

Established in 1986, the school is affiliated to CBSE and caters to students from Lower Kindergarten to Grade 12. English is the medium of instruction. The school is endowed with IT-enabled classrooms, with a single seating table and chair for each of the 40 students, a separate open and a closed auditorium, an equipped medical room, a canteen, a well-maintained and spacious library equipped with e-books as well, individualised education programme, guidance and counselling skills, and 14 different labs (Physics, Chemistry, Biology, 3D, Atal, Space, Khan Academy, Dance, Music, Art, Computer, Mathematics, Social Science and English). The school acknowledges use of different teaching approaches such as the PBL, collaborative learning and competency-based learning. School runs a dedicated skill development and training centre and encourages teacher exchange.

Table 1.
Summary of cases studied

Features	***School P***	***School Q***	***School R***
School type	*Government*	*Private, catering to middle and lower upper class, run by a society*	*Private, caters to affluent class, run by a society*
Grant sanctioned	*March 2019*	*December 2016*	*December 2016*
Physical space	*Compact, gated-school building, no playground*	*Big, gated-school building, big playground*	*Big, gated-school building, big playground*
Students	*Grade V to X*	*Nursery to Grade XII*	*Nursery to Grade XII*
Student socio-economic background	*Lower to Lower middle class*	*Middle to Upper middle class*	*Upper middle to Upper class*
Relative fee comparison	*Least*	*Medium*	*Maximum*
Medium of instruction	*English, Telugu*	*English*	*English*
Sections per grade level	*2*	*4-5*	*4-5*
Average student number per class	*50-60*	*40-45*	*Max 40*
ATL space	*A hall with 2 combined classrooms with computer systems lined along the wall and seating on cloth floor mat. A separate STEM room for resources.*	*Dedicated hall space with table & chair for each individual facing the projector screen. Seating doubles as workspace. Equipment parked in cupboards in hall space.*	*A dedicated long hall space, movable seating and table workspace.*
Management of ATL space	*Dependence on NGO personnel, currently non-functional.*	*Managed by 2 physics teachers, tie-up with an engineering college nearby for regular expert sessions.*	*Managed by 3 physics teachers, tie-up with NGOs and reach out to experts.*
ATL access	*All students, ATL class of 40 mins each*	*Classes on Saturdays reserved for 10-15*	*Time-tabled sessions*

	for 2 days per week for Grades VI to X, each.	*students from each of the Grade VI to X.*	*from Grade VI to X.*

6. ANALYSIS AND FINDINGS

Guided by an exploratory intent, open-coding was used for analysing field observations and notes from conversations with teachers managing the ATLs in their respective schools. Themes developed are preliminary and may get refined as study expands to a greater sample size later.

6.1. Role of school ethos

School ethos seemed to influence the quality of STEM education. Unlike Schools Q and R, School P did not have an impressive infrastructure, yet it housed a dedicated hall-space of two connected classrooms as ATL lab and a separate STEM room. The STEM room maintains resources and is managed by the NGO partner. Students interacted with the resource person from NGO, either twice a month or once a week, depending on the availability of resource persons. The outsourcing of ATL activities to NGOs by the school with only passive oversight by teachers has resulted in non-frequent STEM classes, and little proactive student and teacher participation beyond the time-tabled hours. This manifests a weak co-ownership with little realisable outcomes from ATL engagement.

On the other hand, both Schools Q and R made different arrangements to involve students and teachers in ATL activities. In both cases, responsibility of ATLs was managed by Physics teachers. School Q maintains a dedicated teaching slot every Saturday and encourages a select subset of interested students (about 20) to pursue STEM education. The school has developed partnership with faculty from a neighbouring engineering college to offer training and exposure enabling students to design and construct circuits using electronic chips and gain basics of robotics, coding, etc. Groups of students work on different projects, which are then showcased in annual events like the science day, technology day, etc. School R has an established culture of learning mediated through labs. Time-table slots for ATL figure along with other subjects on working days. Students work in dedicated lab facilities which receive periodic guidance from experts, who bring in concepts and techniques that favour constructional activities and encourage project work. School R periodically organises expert visits and lectures on specific topics. Besides, the dedicated centre attached to the school offers professional skills, training and capacity building to its teachers.

From the school observations, it can be inferred that school ethos significantly impacts how learning is enabled, strengthened and sustained within the ATLs. ATL operations are guided by strategic functioning decisions of administrators, which range from a complete outsourcing to a calibrated engagement with select students or acknowledgement as a distinctive subject domain exposure for students. In all cases, STEM identifies itself as specialised silo along with other disciplines rather than an integrative or interactional learning experience (William, 2011).

6.2. Learning ecology afforded by ATL environments

All three schools had projection and 3D printer facilities but varied in schemes for utilising the ATL resources. School P used teaching methodologies encouraging animation-based resources to aid visualisation and clarify concepts in the sciences. For example, the resource persons used video-clips and models to demonstrate functioning of body joints or core concepts in physics. Scarcely, did students use 3D printers for materialising design explorations or for constructing artefacts. The floor-seating arrangement in hall, limited access to computers, and scant exposure to skill-sets and expertise, placed limits to scope of work in the ATL. In otherwise resource deficit space, this also limited exercise of newer competencies. There are private firms or NGOs which provide package of resource materials and trainings to meet the ATL requirements.

In School Q, interested students registered themselves for STEM experiences. Although kept under vigilance, students had access to 3D printer. The tools for enabling design constructions included certain kinds of materials shelved in one corner. For instance, materials for developing circuits, mini-solar panels and lego blocks. However, there seemed very little cross-utilisation of material resources from the existing science and mathematics lab or even resources from their immediate vicinity. The particular exposure to robotics, and engineering design pushed students to largely identify learning as extension or application of the physical sciences. Teams of 3-4 individuals worked on projects, and topics were discussed between teams and teachers. Students gathered information by surfing the internet and received guidance by consulting experts and teachers. If need be, discussion is raised to the level of an external expert.

Case R represented a different ecology of learning. The dedicated labs housed the 3D printers along with variety of resources for tinkering. The moveable seating facility afforded scope for students to intermingle, use ATL workspace for designing and testing ideas. Technology-enabled classrooms allowed regular computer access and pedagogies of collaborative work were infused in teaching practice. Regular talks, workshop sessions by experts brought fresh ideas to table and ample guidance to work on projects. Students were encouraged to gather information by surfing the internet.

Learning environments with rich infrastructure, access to expertise, and orientation to STEM ideas, significantly inform the ATL practices. In the current neo-liberal era, deployment of definite resources, use of templates, and assessing through project outcomes lead to withdrawal of the agency of teacher and learners. Even in well resourced ATLs, effective engagements are adjudged as projects and their representation in exhibitions at district, state or national levels. In such a scheme, there is little space or credence to reflecting on learning discourses.

6.3. Curriculum and instructional practice

While proposing the ATLs, the government shared a few exemplar modules through its portal. A brief analysis suggests varied principles inform the design of modules and resources. Some modules were sketchy (as slide presentations) while others called upon technology-supported animation and construction (do-it-yourself) tasks. Moreover, the general orientation of STEM curricular resources is information-laden and guided by scripted lesson plans.

Interactions with teachers revealed a prevalent, overarching belief that ATL concerns subject domains of physics and electronics. The ATL activities feed this penetrative rationalisation that teachers themselves are convinced about, reinforcing the idea of technology as predominantly material-driven or involving circuit assemblies, with little scope for other disciplinary domains or social dimensions. As a result, possibility of interactions among STEM disciplines does not occur. Further, the ATLs promulgate the idea of laboratory-based, hands-on learning, reinforcing two ideas: duality between episteme (theory) and techne (practice), and vision of processes leading to innovation. Lab work, timetabled separately from content disciplines reinforces explicit departure from content taught in classrooms and feeds the former idea. Whereas, capital-intensive, resource-rich, and problem to solution oriented formulation as conditions thriving trajectory of innovation feeds the latter. In fact, a threat of sustenance lurks ATLs, which may face the same fate as the desolated science labs with no influx of financial or material resources.

6.4. Expectations from teacher and exercise of teacher agency

The success of ATLs seemed contingent on teachers implanting and sustaining a new ecology within their school cultures. Seeking expectations on teachers help assess how they picture themselves in larger scheme of things. Interactions with teachers in School P, suggested a rather limited understanding of their role as oversight and monitoring of ATL activities. Teachers considered this an additional burden beyond teaching load, involving a follow-up with resource persons from the NGOs.

Three physics teachers shared the responsibility of ATL functioning in School Q. They had freedom to invite experts from neighbouring engineering colleges or institutes. Teachers were conscious of a need to equip themselves with newer knowledge and skills in robotics, 3D printing, and electronics. Working with students, they saw on-the-job learning. This orientation resonates with the idea of teacher as “adaptive expert”, who utilise existing routines effectively to seek and apply new strategies in teaching (Darling-Hammond & Boratz-Snowden, 2007).

School R had ATL responsibilities distributed between teachers and technical staff. Teachers interacted with experts, combined ATL activities with project-based and problem-based tasks. Further, they had scope to enhance their skills through training offered at their centre. Teachers saw STEM activities as extension of their teaching, and even tried to make connections between the STEM disciplines in student projects. But, the efforts towards were more of an afterthought rather than during the process. Envisioning ATLs within teaching workload, invited greater investment of time and responsive shouldering of teaching.

In all three cases, learning through ATLs was project-driven, which brought laurels and greater visibility to school. Such performance dependent learning, offers little scope to deliberate on critical milestones for students’ learning progression.

7. CONCLUSION

This exploratory case study investigated STEM education in ATLs in three different kinds of schools in Hyderabad. Analysis revealed that the quality and texture of STEM education varied in different schools. The situated nature of STEM practices was contingent on school ethos, learning ecology that ATL environment fostered, curriculum and instructional practices followed, and expectations from teachers leading to exercising of their agency. While these aspects are neither complete nor comprehensive, they give first-hand insights into examining the nature of STEM education within ATLs. While ATLs opened school spaces to explore knowledge and skills outside school atmosphere, the peculiar positioning of STEM education within a larger constituency of lab work, placed certain kinds of expectations. STEM engagements were rationalised as another silo within school time-table. Emphasis on tinkering of pre-determined resources offered little scope to design thinking, other than assembling component parts in realising artefactual solutions. Successful projects showcased privileged product over process. Schools were not merely sites for implementing policy directive or an educational initiative, they actively negotiated and even reconstituted the STEM curricular commitment and enaction. A review of STEM practices helped appreciate the influence of contemporary discourses, educational structures, curricular appropriations and contextual adaptations. Establishing reciprocal dialogue between policy makers, practitioners, and researchers on reflexive deliberation of STEM engagements is needed.

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Exploring the Educational Potential of Generative AI in 3D Design within Technology Education

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Abstract

This study categorizes AI-based 3D model generation tools into Text-to-3D, Image-to-3D, and Video-to-3D types, with a particular focus on Text-to-3D tools due to their accessibility and suitability for educational settings. The evaluation criteria include model generation speed, accuracy, user interface intuitiveness, and scalability. Results highlight varying strengths and limitations among the tools, with certain tools excelling in speed, while others perform better in accuracy or file format compatibility. Our findings suggest that AI-based 3D model generation tools hold significant potential to enhance students' creativity, spatial awareness, and interdisciplinary learning. However, for effective implementation, careful attention must be given to curriculum integration, teacher training, and selecting the appropriate tools based on educational goals. This research contributes to the growing field of AI in education by offering valuable insights for educators and policymakers, helping them harness these tools to prepare students for future technological challenges.

Key Words: Generative AI, 3D Design, Technology Education, 3D Modeling, Educational Technology

1. INTRODUCTION

The advancement of the Fourth Industrial Revolution has introduced various innovative technologies applicable to multiple fields. Among these, 3D printing technology is recognized as a transformative innovation in the manufacturing industry (Jandyal et al., 2022). As 3D printing technology continues to evolve, its potential impact on future society is expected to be significant. Therefore, it is essential to cultivate students' basic understanding and familiarity with 3D printing technology, with its applicability spanning various fields (Pearson & Dubé, 2022). Consequently, integrating 3D design technology into school curricula is crucial for developing the technical literacy and expertise needed for the future (Lee et al., 2023). The rapidly advancing generative AI technology is showing new possibilities in the field of 3D design. Generative AI has the potential to revolutionize the 3D modeling process, which is expected to have a significant impact on the methods of technology education.

Due to the increasing complexity and diversification of modern society, acquiring knowledge alone is insufficient to solve problems (Dilling & Witzke, 2020). As future members of society, elementary students in Korea must develop creative problem-solving skills to navigate a rapidly changing environment. In this context, the application of generative AI in 3D design education within elementary technology education is highly relevant and timely. This study focuses on elementary lesson cases that can be utilized in elementary technology education courses at teacher education institutions in Korea. Specifically, it aims to explore the educational potential of generative AI for 3D design in technology education and propose new directions for the future elementary school curriculum. Through this research, it is expected that this study will contribute to enhancing Korean elementary students' creative thinking and problem-solving abilities.

2. LITERATURE REVIEW

2.1. 3D Printing Technology and Education

3D printing technology has garnered attention as an innovative tool not only in manufacturing but also in education. Ford and Minshall (2019) reported that 3D printing is effective in enhancing students' creativity, problem-solving skills, and spatial perception abilities. Particularly in STEM education, the use of 3D printing has been shown to significantly improve student engagement and learning outcomes (Trust & Maloy, 2017). However, due to a lack of appropriate teacher training and educational programs, the adoption of 3D printing technology in education remains at a low level (Üçgül & Altıok, 2023). Learning through 3D printing can promote not only theoretical knowledge but also technical understanding in the actual production process. The integration of 3D printing technology in education can be seen as having high educational value and potential for utilization as it can provide students with a more in-depth learning experience.

2.2. Generative AI and 3D Design

The development of generative AI technology not only revolutionizes the 3D design process but also demonstrates significant potential in the field of education. According to the research by Shreay & Kumar (2024), tools such as text-to-3D model generators can greatly enhance students' creative problem-solving abilities by enabling them to engage in creative design experiments. Similarly, Ford and Minshall (2019) have shown that incorporating 3D printing technology into the classroom improves students' spatial awareness and problem-solving skills. These findings align with the educational potential of generative AI tools, particularly in supporting students' participation in design thinking and iterative learning through text-based 3D model generation.

Text-based 3D model generation technology goes beyond simplifying the design process, offering a learning platform that connects linguistic and spatial reasoning abilities. Liu et al. (2023) developed an AI system that generates 3D models from natural language descriptions, empowering students to visualize and create complex 3D models without the need for advanced technical knowledge. This approach helps students focus on the conceptual aspects of design and creativity while also improving their creative thinking and technical literacy (Dilling & Witzke, 2020). These creative learning tools also support students in better adapting to the demands of future technological advancements.

Generative AI tools enable educators to create immersive learning environments that foster interdisciplinary exploration and application of knowledge. Through such environments, these tools contribute to students' holistic cognitive development. This study goes beyond mere tool evaluation, aiming to discuss how generative AI can be strategically integrated into technology education to enhance students' creative thinking and problem-solving abilities.

2.2.1. Text-to-3D Model Generators

Text-to-3D model generators allow the creation of 3D models based on user-provided text descriptions. By utilizing Natural Language Processing (NLP) technology, these tools interpret the descriptive text and generate corresponding 3D models. This approach is particularly useful for visualizing ideas, creating storyboards, and developing educational materials. It is also widely used in fields such as architecture and design. According to Shreay & Kumar (2024), these tools provide students with opportunities to visually express creative ideas, facilitating their understanding of complex design concepts. Liu et al. (2023) found that when creative thinking is directly linked to learning, it enhances students' problem-solving abilities, highlighting the importance of Text-to-3D tools in fostering creative thought processes.

2.2.2. Image-to-3D Model Generators

Image-to-3D model generators use AI systems to analyze 2D images and transform them into 3D structures. This method can create complete 3D models from photos or drawings and is commonly used in industries like computer vision, virtual reality, and entertainment. Ford and Minshall (2019) demonstrated that 3D printing technology in education enhances students' spatial awareness and problem-solving skills, suggesting that Image-to-3D tools can be valuable in helping students explore and understand 3D environments that mimic real-world scenarios.

2.2.3. Video-to-3D Model Generators

Video-to-3D model generators are primarily employed in fields such as robotics, autonomous vehicles, and augmented reality, where they create 3D models from video data. These tools analyze video clips to capture the movement and structural changes of objects over time, and based on this analysis, generate 3D models. This approach is particularly useful for modeling dynamic scenes or moving objects, sports analysis, and motion capture. Liu et al. (2023) emphasized the ability of these tools to process complex motion data, suggesting that they can assist students in understanding physical concepts related to movement within an educational context.

3. METHODOLOGY

This study adopted a Mixed Methods Approach to explore the educational potential of AI-based 3D model generation tools. The purpose of this approach was to provide a comprehensive understanding by combining content analysis and functionality analysis.

3.1. Content Analysis

A scoping review was conducted to identify the current state and types of AI-based 3D model generation tools. The review examined relevant literature published in the last five years from major academic databases, including IEEE Xplore, ACM Digital Library, and ScienceDirect, as well as industry reports. Keywords used in the search included "AI-based 3D modeling," "generative AI for 3D design," "Text-to-3D," "Image-to-3D," and "Video-to-3D." This process enabled the classification of major types, features, and use cases of AI-based 3D model generation tools.

However, there was a limitation in the availability of sufficient academic literature specifically addressing certain AI-based 3D model generation tools, and relevant data was often limited. This was largely due to the fact that these tools rely primarily on informal online communities or user reviews and are less frequently covered in academic research. As a result, further empirical research is necessary for a more in-depth analysis of these tools. To address this limitation, this study also selected online tools through expert consultation and practical judgment. The criteria for selecting these online tools were as follows: (1) ease of use in educational settings, (2) availability of free or partially free services for students, and (3) compatibility with 3D modeling software, including the ability to export files. Based on these criteria, six text-to-3D model generation tools were selected for further analysis.

3.2. Functionality Analysis of AI-based 3D Model Generation Tools

A functionality analysis was conducted on the selected AI-based 3D model generation tools. The evaluation criteria included model generation speed, accuracy of the generated models, intuitiveness of the user interface, and the ability to generate models with varying levels of complexity (scalability). To assess these factors, each tool was tested by generating a 3D model of a smartphone standwith the same level of complexity.

The smartphone stand was chosen as the prompt because it is commonly used in elementary technology education as a practical exercise. This task allows students to learn fundamental 3D design concepts while engaging in creative design and functional problem-solving. Additionally, the task incorporates key elements of technology education, such as design process, prototyping, and iterative problem-solving, making it a valuable educational tool.

Using a different prompt could lead to varied results. For example, prompts such as chairsor cars, which are more complex, would require the AI tools to handle additional details and structural elements, potentially leading to greater differences in accuracy and scalability. Conversely, simpler objects such as cupsor desk supportsmight demand less processing power from the tools, resulting in less noticeable differences in generation speed and accuracy.

The smartphone stand represents a moderately complex and functional object, making it an ideal prompt for evaluating the performance of various AI-based 3D model generation tools. By using this prompt, the study was able to assess how well each tool could be utilized in an educational setting, and the results were quantitatively measured to provide comparative insights. Through this methodology, the study aims to offer in-depth insights into the current capabilities of AI-based 3D model generation tools, their educational potential, and directions for future development.

3.3. Accessibility of AI-based 3D Modeling Tools

In this study, we focused on the usability of AI-based 3D modeling tools that do not require complex programming setups, such as Python, for educational purposes. Tools like Shap-E, Luma AI, and Meshyare web-based and can be accessed directly through a browser without the need for additional installations. These features make the tools particularly suitable for elementary school students, as they can participate in practical activities without the technical challenges associated with software installation or programming.

Unlike some Python-based software that may require advanced technical knowledge, these web-based tools allow users to create 3D models simply by inputting text descriptions. This significantly lowers the entry barrier for educators and students, enabling seamless integration into classroom activities. Therefore, this research emphasizes the practicality and ease of implementation of AI-based 3D modeling tools in elementary school technology education.

4. RESULTS

4.1. Analysis of AI-based Text-to-3D Model Generation Tools

In recent years, AI-based 3D modeling has rapidly evolved, enabling the automatic generation and optimization of complex 3D models based on user input and various data types. A number of AI-driven 3D model generation platforms and tools have emerged globally, playing a significant role in advancing the field (Liu et al., 2023). AI-based 3D model generators leverage artificial intelligence and machine learning algorithms to create three-dimensional (3D) models from inputs such as text, images, and video. This study focused on analyzing six widely-used Text-to-3D model generation tools to explore their potential for educational integration, particularly in school environments, where accessibility and ease of use are critical.

Table 1 presents a comparative analysis of the selected AI-based 3D model generation tools, covering generation types, pricing policies, and supported export formats. Each tool is examined for its potential to meet the diverse needs of educational projects, from introductory design exercises to more advanced 3D modeling activities. The variety of generation types and export options provides educators with flexibility, enabling them to choose the right tool for their specific classroom requirements.

Table 1.
AI-based 3D Model Generation Tools

Tool	*Generation Type*	*Link*	*Price Policy*	*Export Support*
Shap-E	*Text-to 3D* *Image-to-3D*	*https://huggingface.co/spaces/hysts/Shap-E*	*Free*	*glb*
Luma AI	*Text-to 3D* *Image-to-3D*	*https://lumalabs.ai/genie?view=create*	*Partially free*	*fbx, gltf, usdz, blend, stl, obj*
Masterpiece X	*Text-to 3D*	*https://www.masterpiecex.com*	*Partially free*	*fbx, glb, usdz*

Meshcapade	*Text-to 3D*	*https://meshcapade.com*	*Partially free*	*fbx, obj*
3DFY AI	*Text-to 3D*	*https://app.3dfy.ai*	*Partially free*	*fbx, glb, blend*
Meshy	*Text-to 3D*	*https://www.meshy.ai*	*Partially free*	*fbx, glb, usdz, blend, stl, obj*

Table 1 provides a detailed summary of the tools evaluated in this study. These tools vary in their pricing policies—some offering free versions with limited functionality, while others are partially free with additional paid features. Export format support is also a critical factor in determining the applicability of these tools in various educational contexts. Educators can leverage the versatility of tools like Luma AI and Meshy, which support multiple file formats, to facilitate seamless integration with other software used in classroom settings.

In summary, this analysis highlights the strengths and limitations of each tool, providing educators and practitioners with clear guidance on how to choose the best AI-based 3D model generation tools for their specific educational or project-based needs. Tools like Shap-Eand Luma AIare particularly well-suited for tasks requiring quick and simple model generation, while more feature-rich platforms like Meshyoffer greater flexibility for more advanced design projects.

4.2. Functionality Analysis of AI-based 3D Model Generation Tools

A functionality analysis was performed on the selected AI-based 3D model generation tools, evaluating them based on key criteria such as model generation speed, accuracy of the generated models, user interface intuitiveness, and the ability to generate models of varying complexity (scalability). Each tool was tested by generating 3D models of the same complexity, and the results were quantitatively measured. This analysis aimed to provide in-depth insights into the capabilities of AI-based 3D model generation tools, their potential use in educational settings, and recommendations for further development.

The analysis of six AI-based Text-to-3D model generation tools revealed distinct characteristics and both strengths and weaknesses for each tool. Regarding model generation speed, Shap-E, Luma AI, and 3DFY AIwere the fastest, with generation times ranging from 10 to 15 seconds. In contrast, Masterpiece Xand Meshytook over 2 minutes, making them slower by comparison. In terms of accuracy, Luma AIand Meshywere rated 'very high,' indicating excellent performance, while Masterpiece Xwas rated 'high.' However, Shap-Eand 3DFY AIwere rated 'low' in accuracy, and Meshcapadereceived a 'moderate' rating.

For file format support, Luma AIdemonstrated the highest compatibility, supporting six different export formats, while Shap-Eand Meshcapadeshowed more limited support, offering just one or two export formats respectively. As for editability, Luma AI, Masterpiece X, Meshcapade, and Meshyprovided editing options for generated models, while Shap-Eand 3DFY AIdid not allow for model editing.

The analysis of models generated based on the prompt "A smartphone stand shaped like a cartoon cat, with a wide bottom" revealed that most tools were capable of producing suitable models. In particular, Luma AIand Meshygenerated outputs that were closely aligned with the prompt, while Meshcapadewas identified as a tool specifically designed for generating avatars, making it less versatile for other types of models.

Overall, Luma AIdemonstrated the best overall performance, excelling in generation speed, accuracy, file format support, and editability. Meshyalso performed well in accuracy and editability but had room for improvement in generation speed. In contrast, Shap-Eshowed fast generation speed but was limited in terms of accuracy and scalability, while Masterpiece Xand 3DFY AIexhibited mid-level performance. These results suggest that when selecting AI-based 3D modeling tools for educational settings, it is essential to choose tools that best fit the specific use case and learning environment.

Table 2 below summarizes the functionality analysis results for the six AI-based Text-to-3D model generation tools. The table provides a detailed comparison across critical metrics, including model generation speed, accuracy, number of supported export formats, editability, and the example models generated from the prompt "A smartphone stand shaped like a cartoon cat, with a wide bottom."

4.3. Strategies for Improving Accessibility of AI-based 3D Modeling Tools in Education

To effectively introduce AI-based 3D modeling tools in educational settings, improving accessibility is crucial. Drawing inspiration from widely used elementary school tools like TinkerCAD, it is necessary to develop an integrated platform for AI-based tools that incorporates Learning Management System (LMS) functionalities. This integrated platform would provide a user-friendly interface for teachers, allowing them to leverage the strengths of various AI tools while systematically managing the learning process.

Combining learning management features with educational 3D modeling tools greatly aids in tracking students' progress, providing individual feedback, and managing collaborative projects. By incorporating these features into AI-based 3D modeling tools, teachers can more effectively monitor and support their students' learning processes.

However, this approach may result in paid services due to the need for API utilization and additional feature integration in AI tool platforms. To ensure educational equity and enhance students' access to cutting-edge technology, it is advisable for governments to support school-level service usage through educational support budgets. Such an integrated platform could include content filtering features tailored to school and grade-specific curricula, potentially preventing adverse effects and providing age-appropriate learning experiences.

In conclusion, the development of a teacher-friendly AI-based 3D modeling platform with integrated educational management features, coupled with government support, can significantly enhance the accessibility and effectiveness of these technologies in educational settings. This approach has the potential to revolutionize the integration of 3D modeling and AI technologies into curricula, providing students with crucial future skills in a safe and controlled learning environment.

Table 2.
Functionality Analysis Results of AI-based Text-to-3D Model Generation Tools

Tool	*Model Generation Speed (Time)*	*Generated Model Accuracy*	*Generated Model Accuracy*		*Generated Model Example (A smartphone stand shaped like a cartoon cat, with a wide bottom)*
			Number of Supported Export Formats	*Editable*	
Shap-E	*Fast (10 seconds)*	*Low*	*Low*		
			1	*Not editable*	
Luma AI	*Fast (15 seconds)*	*Very high*	*Very high*		
			6	*Editable*	
Masterpiece X	*Moderate (2+ minutes)*	*High*	*Moderate*		
			3	*Not editable*	
Meshcapade	*Moderate*	*Moderate*	*Very low*		*(Avatar generation only)*
			2	*Editable*	
3DFY AI	*Fast (15 seconds)*	*Moderate*	*Low*		

			3	Not editable	
Meshy	Moderate (2+ minutes)	High	Very high		
			6	Editable	

5. DISCUSSION

AI-based 3D model generation tools are considered to have significant potential to enhance various student skills in elementary technology education. According to the study by Hutson & Robertson (2024), AI generative tools that employ prompt engineering effectively foster students' creative thinking and 3D design abilities. Specifically, text-to-3D model generation features can help students quickly visualize their ideas, thereby greatly enhancing their creative expression. This aligns with the findings of Shreya & Kumar (2024) in the field of interior design, where AI tools are noted for their efficiency, helping users implement visual ideas more quickly and effectively.

However, successfully integrating these tools into the educational environment requires careful consideration of several key factors. First, aligning the use of AI-based tools with curriculum goals is essential. These tools should be seen not merely as technical aids, but as instruments that support specific educational objectives. Second, teacher capacity building through training and support is critical. Teachers need not only technical understanding but also pedagogical strategies to effectively incorporate these tools into the classroom. Lastly, it is important to choose tools that match the achievement standards and learning goals for each school grade level. Each tool has its own strengths and limitations, so it is necessary to select tools based on the educational context and students' needs.

Moreover, there is a need to improve accessibility to AI-based tools. Learning management system (LMS) functionality should be integrated into AI-based tools, similar to the widely used TinkerCAD in elementary schools. A unified platform that offers a user-friendly interface for teachers would help them leverage the strengths of various AI tools while systematically managing the learning process.

Combining educational 3D modeling tools with LMS features would provide significant advantages in tracking students' progress, offering individualized feedback, and managing collaborative projects. However, such integrated platforms may require API use and the inclusion of additional features, making them likely to be offered as paid services. Therefore, to ensure educational equity and provide students with access to advanced technologies, government funding for schools to support such services is necessary.

In conclusion, AI-based 3D model generation tools hold great potential as resources for enhancing students' various skills. However, realizing this educational potential requires ongoing research and development, as well as empirical studies that assess the educational effectiveness of these tools. Given the rapid advancement of AI technology, continuous monitoring and evaluation are also essential. Through these efforts, AI-based 3D modeling tools can become an important resource in the educational field. In particular, the development of teacher-friendly platforms integrated with educational management functions and government support for accessibility will contribute to improving both the effectiveness and reach of these technologies, providing students with a safe and structured learning environment.

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Development of an Educational Program using Project-Based Learning in the 'Medical Device Classification' Unit of the NCS 'Medical Device Regulatory Affairs' Subject

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Abstract

This study aimed to create a project-based learning (PBL) educational program for the "Medical Device Classification" unit in the "Medical Device Regulatory Affairs" subject at a specialized high school in Korea, using the PDI model. The development process included preparation, development, and improvement stages. In the preparation stage, the 2022 Revised Curriculum, NCS(National Competency Standards) Learning Module, and PBL were analyzed to establish learning topics and goals. During development, the PBL process was employed to create educational programs, teaching plans, and presentation materials, which were validated by experts. In the improvement stage, the program was revised based on preliminary and field test results. The study highlighted the lack of PBL programs for this subject and developed a six-session program focusing on key learning elements like item group determination and grading standards. Teaching plans, presentation materials, and various student feedback tools were created and utilized. The program was modified, supplemented, and improved through preliminary tests of the developed program. The program was developed by analyzing and reflecting the knowledge information processing competency, competency, student satisfaction, student reflection journals, and student interview questionnaires through the application of field tests.

Key Words: Vocational Education, PBL(project-based learning), NCS(National Competency Standards), specialized high school

1. THE PURPOSE OF THE STUDY

1.1. The objectives and content of the study

The purpose of this study is to develop an educational program using project-based learning for the 'Medical Device Classification' unit of the 'Medical Device License and License' subject in the electrical and electronic specialized curriculum of the '2022 Revised Curriculum'.

The specific contents of the study to achieve the purpose of the study are as follows.

First, a project-based education program development model is established by analyzing the curriculum for medical device licensing and licensing subjects in electrical and electronic subjects in the project-based learning literature and the "2022 Revised Curriculum".

Second, through the established project-based learning education program development model, teaching and learning guidance plans, teaching and learning materials, and class-related materials are developed according to the procedure.

Third, the developed project-based learning education program is applied to the class and analyzed to confirm the results of knowledge information processing capabilities and job capabilities in the NCS "Medical Device Regulatory Affairs" field among the core competencies presented in the "2022 revised curriculum".

1.2. Terms And Definitions

1.2.1. Specialized High School

Specialized high schools are defined as high schools (hereinafter referred to as "specialized high schools") that specialize in experience-oriented education, such as education or natural field practice, for students with similar talents, aptitudes, and abilities (Article 91 (specialized high schools) of the Enforcement Decree of the Elementary and Secondary Education Act (Presidential Decree No. 33381, April 19, 2023).

In this study, specialized high schools are limited to specialized high schools under Article 91 (1) of the Enforcement Decree of the Elementary and Secondary Education Act, which aims to cultivate talents in the industrial field.

1.2.2. NCS(National Competency Standards)

The NCS (National Competency Standards) is a systematization of the contents of knowledge, skills, and literacy required to perform jobs in industrial sites by industry sector and level. It refers to the standardization of the ability (knowledge, skill, and attitude) necessary to successfully perform a job in the industrial field at the national level (Ministry of Education, Korea Vocational Competency Research Institute, 2023, p. 5).

1.2.3. NCS learning module

The NCS learning module refers to teaching and learning materials that are designed to utilize the competency units presented in the NCS in education and vocational training, and the NCS learning module refers to the learning content required to enhance learners' job skills based on the knowledge, skills, and work procedures presented in the NCS (Ministry of Education, Korea Vocational Competency Research Institute, 2023, p.8).

The NCS learning module is defined as having the status of recognized books in the NCS-based curriculum, and is currently used as recognized books in specialized high schools and Meister High School (Regulations on Curriculum Books (Presidential Decree No. 32547 on March 22, 2022) Article 17 (Scope of Use of Recognized Books, etc.).

2. ARTICLE LAYOUT

The appropriate sections for articles will vary depending on the nature and intent of the article. In general, authors should aim to provide the following information:

(i) Introduction: This section should provide a broad overview of the research area and In Korea, the mid- to long-term "National Competency Standards Development and Utilization Plan" was established jointly by relevant ministries in June 2012, and NCS development and NCS learning module development, which were promoted as national tasks to "create competency-oriented social conditions," are continuing until now (Jeong Hyang-jin et al., p. 3).

(ii) The Ministry of Education revised and announced the NCS-based high school vocational curriculum in 2015 and applied it from freshmen in 2018. In 2016, the NCS-based high school vocational curriculum was applied first, focusing on practical subjects, and in 2017, NCS was revised and supplemented, and practical major subjects were reorganized in the 2015 revised curriculum. Education on practical subjects is being conducted through the 2022 revised curriculum (Ji-young Kim, 2017, p. 32).

(iii) The "2022 Revised Curriculum" requires students to design and operate teaching and learning so that they can cultivate core competencies through in-depth learning (Ministry of Education, 2022a, p. 10). The project method corresponding to the student-centered learning method for this corresponds to today's Project Based Learning (PBL), and it is a learning method that provides or enhances internal motivation, responsibility, positive self-concept, cooperation, problem-solving ability, various inquiry and expression skills, and experiential learning opportunities to learners (Daehyun Kim et al., 1999, p.15). Project-based learning is presented as a representative method of student-centered learning that provides student-led learning experience opportunities to explore, organize, and present data in the process of learning in the "Electric and Electronic Specialized Curriculum" of the 2022 Revised Curriculum (Ministry of Education, 2022b, p. 929).

(iv) Literature Review : Specialized high schools, a representative secondary vocational education institution in Korea, reorganize NCS learning modules according to the national-level curriculum and use them as practical subject textbooks. However, there are cases where the level and scope of the learning module do not match the high school level (Miran Kim et al., 2017, p. 38). In this situation, education on NCS-based practical subjects for specialized high school students is required to apply student-centered learning methods to cultivate six core competencies (self-management competency, knowledge information processing competency, creative thinking competency, aesthetic emotional competency, cooperative communication competency, common competency), and digital competencies presented in the 2022 revised curriculum.

(v) The NCS 'Medical Device Regulatory Affairs' Subject requires understanding the country's regulations based on general knowledge of the safety and effectiveness of domestic and foreign medical devices, and developing the ability to perform and continuously manage various major duties for the medical device (Ministry of Education, 2022b, p. 915). Despite the high importance of this, related research on student-centered learning methods using project-based learning for the 'Medical Device Regulatory Affairs' Subject is very insufficient.

(vi) Therefore, in this situation, we intend to develop an educational program using project-based learning corresponding to student-centered learning methods for NCS 'Medical Device Regulatory Affairs' Subject to prepare for the future society in specialized high schools and educate them as talents in the advanced medical device industry.

(vii) Methodology: In this study, in order to develop a project-based learning education program using the NCS learning module for the 'medical device authorization and permission' subject in the electrical and electronic specialized subjects of the 2022 revised curriculum in Korea, the detailed contents of the model were modified and supplemented according to the preparation phase, development phase (D), and improvement phase (I) based on the PDI model of Mager & Beach (1967).

In the development stage (D), an educational program was developed by revising and supplementing the six-step project learning process of Kim Dae-hyun (1999) so that it could be applied to secondary vocational education (page 17). The PBL program development procedure of this study is shown in Figure 1.

Figure 1.

Procedures for Developing Educational Programs Using Project-Based Learning

Procedure	Main Contents	
P (Preparation)	• Curriculum Analysis	• Reviewing the 2022 Revised Curriculum
	• Analysis of NCS Learning Module	• Analysis of NCS Medical Device Authorization and Authorization Subjects
	• Project-Based Learning Analysis	• Analysis of the characteristics and development procedures of project-based learning
	• Set learning topics and learning objectives	• Setting the elements and directions considered for program development
D (Development)	• Development of project-based learning education programs	Select a Topic ▽ Plan ▽ Practice ▽ Evaluation
	• Development of class-related materials	• Development of teaching and learning courses • Development of instructional materials • Development of a Class Satisfaction Questionnaire
	• Review and select inspection tools	• Review and select inspection tools for core competencies and job competencies
	• Expert Validation and Program Complementation	• Expert Validation Conducted • Expert Validation Results Analysis and Program Complementation
I (Improvement)	• Preliminary examination of a program	• Preliminary examination of a small group of students • Collection of preliminary test data - Satisfaction Questionnaire • Program preliminary testing to analyze results and improve programs
	• Program on-the-job test	• Running program field trials • Collection of quantitative data - Pre- and post-examination - Student Class Satisfaction Questionnaire • Collection of qualitative data - a student reflection journal - Participating student interview questionnaire
	• Program Development Completed	• Analysis and reflection of quantitative and qualitative data • Complete development of education programs using project-based learning

(i) Results: In this study, by applying the 'PDI model' and 'project-based learning procedure' to the 'Medical Device Rating Classification' of NCS 'Medical Device Regulatory Affairs' subject, an educational program using project-based learning was developed for 18 third-year students of specialized high school located in Seoul, Korea. In the 'Understanding the Grade Classification Criteria' learning element of the 'Medical Device Rating Classification' of the NCS 'Approved Subject', an educational program using project-based learning was developed for a total of six sessions.

In this process, a teaching and learning process plan, presentation class materials, student class satisfaction questionnaire, student reflection journal, and participating student interview questionnaire were developed and utilized. In the development process, the validity of the educational program using project-based learning was revised and supplemented through expert verification, and preliminary and field tests were conducted with improved programs.

Among the core competencies required by the 2022 revised curriculum, the positive contents of the program are confirmed through pre-test and post-test, student satisfaction questionnaire for knowledge information processing competency and NCS-based job competency. And based on the analysis of the student reflection journal and the results of the student interview questionnaire survey, the development of the educational program using project-based learning was completed.

(ii) Discussion: Based on the results of this study, I would like to make the following suggestions.

First, in this study, an educational program was developed for 18 third-year high school students majoring in a specialized high school located in Seoul, Korea. There is a need for research on the development of educational programmes using project-based learning for Meister High School students in secondary vocational education.

Second, it is necessary to study the development and application of educational programs using project-based learning for various NCS-based specialized subjects in the "2022 Revised Curriculum".

Third, research is needed to develop PBL-based education programs for six core competencies and NCS job competencies and verify their effectiveness in the "2022 Revised Curriculum" required to prepare for the future society of various NCS specialized subjects.

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Curriculum Integration: Café Case Study – Te Kāuta

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Abstract

Curriculum integration is a popular yet challenging approach that requires engaging with multiple subject areas in a meaningful and cohesive way. This paper, the second in a series, focuses on a case study from a larger dataset of teaching artefacts used in both English-medium and Māori-medium contexts for students aged 5-12 years in Aotearoa New Zealand. The case study, titled Te Kāuta, involved students designing, planning, and running a café as part of an integrated unit of learning over the eight-ten weeks of the school term. The project emphasised Hangarau (Māori-medium Technology) as the foundation for integrating other disciplines, including mathematics, health, science, and social studies.

Using an autoethnographic lens, this paper explores the planning, delivery, and student engagement across two iterations of the Te Kāuta unit. The study refines emerging principles of effective curriculum integration, highlighting the role of real-world applications, scaffolded learning through tuakana-teina relationships, and the importance of community involvement. This research builds on the principles introduced in the first paper of the series and contributes to ongoing conversations about integrated learning practices in both Māori-medium and broader educational contexts.

Key Words: curriculum integration, Māori-medium technology, Hangarau, autoethnography, integrated learning.

1. HE WHAKATAKINGA: INTRODUCTION

This paper, the second in a series, focuses on curriculum integration in the primary and intermediate sectors in Aotearoa New Zealand, teaching and learning with children aged 5 to 12. Two key curriculum frameworks are implemented in classrooms: The New Zealand Curriculum for English-medium contexts (Ministry of Education, 2017b) and Te Marautanga o Aotearoa for Māori-medium contexts (Ministry of Education, 2017a). The guiding question for this paper is:

> **How can thematic planning purposefully integrate across curriculum areas, starting with a Hangarau [Māori-medium Technology] need or opportunity?**

The methodology employs an autoethnographic approach (DeLorme, 2018; Whitinui, 2014), with a focus in the literature on STEM curriculum integration in indigenous contexts. Links will be made to the general literature related to curriculum integration (Lemon & Hanly, 2023). Then a specific unit is analysed in relation to the literature, in refining a set of initial principles for curriculum integration – in the classroom context. The paper analyses a unit delivered in 1999 and again in 2007, in which students designed and ran a café. This unit was delivered with children in 1999 and then, due to children's requests, it was delivered in 2007 (the class had enjoyed the book that the first students had made for the classes' library corner and the interviews with past students raised briefly below and asked if they could run a café). We have selected this as an exemplary unit. It was one of the first topics of conversation raised by past students when we were recording footage in the build-up to our classes' 10-year anniversary:

> "I loved the Kāuta!"
> "Yeah, it was so fun."
> "And we got to eat all the kai afterwards!"
> "…having real people…"
> "Kia whāngai i a rātou [To look after]."

It is valuable taking a closer look at a dataset where the data has not been evaluated but needs to be evaluated. What is it about this unit that made it so memorable for students? Tamsin Hanly, as lead teacher and Ruth Lemon, as kaiārahi i te reo [classroom assistant and language mentor] and parent for the second iteration – reflect on the unit.

2. METHODOLOGY

Ko wai māua? Nō hea māua? Ko Endeavour te waka. Ko Aīrihi, ko Ingarangi ngā iwi. Ko Ngāti Pākehā te hapū. Ko Maungawhau te maunga ki taku taha. Ko te Waitematā te moana ki taku taha. Kei Tāmaki makau rau te kāinga. Nō Aotearoa ahau. Ko Tamsin taku ingoa. I te taha o tōku pāpā ko Taniwha te maunga. Ko Tāpapa te awa. Ko Kohatutaka te hapū. Ko Ngāpuhi te iwi. I te taha o tōku māmā ko Kereti te moana. Ko Kōnihi, ko Kōtimana, ko Airihi ngā hapū. Ko Ngāti Pākehā te iwi. Ko Ruth taku ingoa. Tēnā koutou, tēnā koutou, tēnā tatou katoa.	Who are we? Where are we from? The Endeavour brought me to Aotearoa NZ. I am Irish and English. The Pākehā people (NZ settlers) are my extended family. Maungawhau is the mountain by my side. Waitematā is the ocean by my side. My home is in Auckland. I am from Aotearoa NZ. Tamsin is my name. On my dad's side I connect to the mountain Taniwha. Tāpapa is the river. Kohatutaka is the extended family. I belong to Ngāpuhi. On my mum's side I connect to the Celtic Sea. Cornwall, Scotland and Ireland are my extended families. I connect to the Pākehā people, who settled in NZ. Ruth is my name. Greetings to you all as we engage in this paper together.

Autoethnography is a research methodology with storytelling at its heart (Drawson et al., 2017; DeLorme, 2018; Lashua & Fox, 2006; McIvor, 2010; Stewart, 2024; Whitinui, 2014). The autoethnographic lens supports the analysis of integrated learning by offering a deeply personal and reflective approach that combines our lived experiences within a broader socio-cultural, educational context, facilitating the analysis of integrated learning by focusing on the interplay between individual experience, cultural practices, and educational structures. Our stories of coming to write these case studies is a long one, however, a key part of the story lies in our work together with student teachers. Tamsin led the way into higher education, starting as a part-time lecturer with Te Puna Wānanga – The School of Māori and Indigenous Education at the University of Auckland. I followed her into the sector three years later. We lectured together in the 3-year Bachelor of Education, introducing student teachers to a Māori worldview: some language, histories, and cultural practices to inform their future classroom practice. We discussed strategies – what could we do to scaffold the English-medium student teachers' understanding? Our experience of teaching was that te ao Māori [a Māori worldview] could be the starting point and the foundation of all teaching and learning. We informally shared these case studies with student teachers to support them in making connections. We both hold the belief that ideas are a teacher's currency, and so, a secondary aim, is to share ideas with other teachers. The third aim of this paper is to refine the principles of best practice, continuing the conversation about curriculum integration and what that looks like in classroom implementation of the curriculum.

3. METHOD

This research utilises an autoethnographic perspective to examine a series of teaching resources, including plans, student artefacts, and modelled and shared classroom artefacts. The available dataset represents 25 years of teaching practice across English-medium and Māori-medium contexts with year one to eight students (aged between 5 and 12 years of age), and consisted of many different document types, as outlined in Table 1. The café or kāuta unit was selected as a second case study, due to the memorability of the unit to students, and due to the authors' belief, that Hangarau (Māori-medium Technology) is a robust means of planning for integrated learning across the curriculum. These artefacts for the selected unit of learning support the refinement of initial principles for best practice.

Table 1
The Types of Data in the Available Dataset

Plans	*Student artefacts*	*Modelled and shared artefacts*
Unit plans	Exemplars	Brainstorms
Weekly plans	Photographs	Drafted songs
Year overviews	Videos	Writing drafts
Written rationales for classroom delivery	Audio recordings	Exemplars
Press coverage of the café	Booklets	Daily success criteria
School journal 'articles'	Powerpoint presentations	Small group projects
	10-year anniversary interview content	Centenary book interview content

Data analysis utilised thematic coding, and the autoethnographic lens facilitated a focus on understanding the meaning and significance of the integrated learning experiences from multiple perspectives, as the researchers drew on personal experiences to make sense of the data, linking the emerging themes back to Jacob's (1989) model of interdisciplinary learning and Kelley and Knowles' (2016) approach to teaching STEM content across multiple domains.

4. LITERATURE

In Lemon and Hanly (2023), we focused on the evolution of the term curriculum integration and its connection to the Māori-medium educational goals of language revitalisation and regeneration. This paper shifts to exploring integrated STEM education (Science, Technology, Engineering, and Mathematics) framed as inquiry or problem-solving, with a focus on its application in Māori-medium contexts.

We acknowledge Stewart's (2023) argument that replacing a universalist approach to 'Western science' with a relativist or 'Kaupapa Māori' approach may not benefit students. Our approach begins with a Kaupapa Māori foundation and incorporates other knowledge bases. Therefore, it was not necessary to discuss literature on integrating Indigenous perspectives into mainstream or English-medium contexts, as argued in contexts such as Métis teachers' experiences in Canada (Gillies, 2021) or the integration of Indigenous and environmental pedagogies (Kulnieks et al., 2013).

Researchers contest definitions of curriculum integration, STEM integration, and the goals of STEM education. Curriculum can be viewed as interdisciplinary, crossdisciplinary, multidisciplinary, pluridisciplinary, or transdisciplinary (Jacobs, 1989). Rennie et al. (2012), through ten integrated STEM case studies, identified six attributes that significantly impact program success:

- Stable learning environments with well-established teaching teams and communities.
- Strong leadership from principals, team leaders, or teachers.
- Close links between team activities and the classroom when multiple teachers are involved.
- Quality planning time.
- Flexible timetables allowing teachers to manage student grouping, teaching time, and spaces.
- Community links ensuring learning is relevant and involves community members.

Jacobs (1989) proposes a model to guide planning by determining an organising centre (such as an event—in our case study, running a café for a week) and brainstorming questions and learning possibilities. Capraro et al. (2013) emphasise Problem-based Learning in STEM education. We connect Jacobs' (1989) model with Kelley and Knowles' (2016) definition, which teaches STEM content from multiple domains, using an organising centre and guiding questions to enhance student learning.

5. CASE STUDY: TE KĀUTA, 1999

This unit was first delivered from July to September in Term 3 of 1999 in a whānau rumaki reo, a Māori-medium immersion classroom where 80-100% of the teaching and learning experiences are delivered in te reo Māori, with mātauranga Māori as the foundation of all teaching. Tamsin Hanly was the lead teacher. In 1999, there was one composite classroom of 27 students, with junior students (nohinohi) aged 5-7 and senior students (tuakana) aged 8-11, studying at levels 1-4 of Te Marautanga o Aotearoa. While literacy and numeracy were taught separately in ability groups, all other subjects were taught in mixed-ability groups. The class prepared to run a café at school for the last week of term, involving eight weeks of integrated learning.

Guiding questions included:

- What do you eat and why? Consider taste and cost.
- How do people choose where to eat a meal?
- How does heat change food?
- How do shelf-life and packaging impact food?

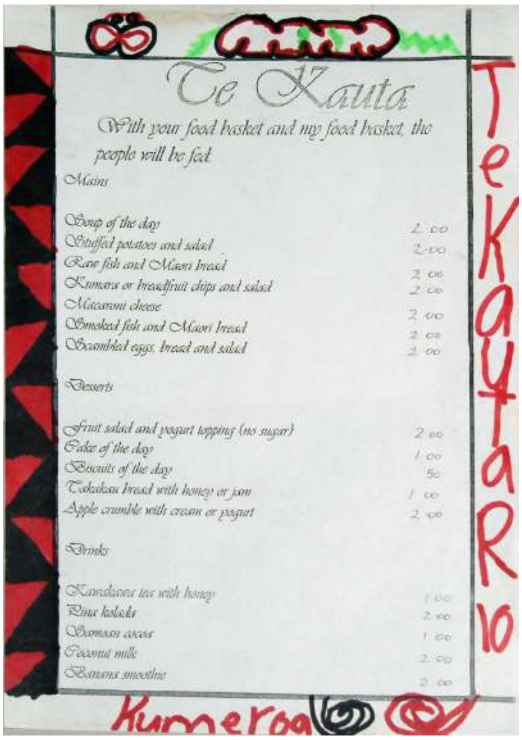
Figure 1. Artworks of Our Impressions of Te Ao Kōhatu

Education Outside the Classroom [EOTC] has been identified as an important component of education in New Zealand. The second-tier material developed to support the two nationally mandated curriculum frameworks defines EOTC as encompassing all curriculum-based learning and teaching taking place beyond “the four walls of the classroom” (Ministry of Education, 2016, p. 1). The unit started with a focus on tikanga (cultural practices) and health. Students studied karakia kai (prayers for food) and examined their sugar consumption through food diaries. They explored balanced diets and designed a survey to understand food preferences and pricing from other classes. In groups of three, they recorded preferences, tallied responses, graphed results, and used this data to design a healthy and tasty menu. They also included traditional Māori cuisine like rēwena (traditional leavened bread) and pūhā (Sonchus kirkii or prickly sowthistle).

Figure 2. A Page from the Classes' Big Book

The class visited a Māori café, Te Ao Kōhatu, to interview the owners about running a café. They identified the importance of ambiance (see Figure 1) and engaged in community connections, learning to weave harakeke (flax) place mats and flowers with their mothers, while seniors wove rourou (baskets). They designed a logo, screen-printed tablecloths, and uniforms, and each contributed artworks for the café's decor. A class vote determined the café’s name, which was used in advertising and menus (see Figure 2). Reading and language lessons focused on recipes, food science, and waste recycling, with students writing journal entries and creating a big book for the library (see Figure 3). Guests to the café had resulted in other writings about Te Kāuta, from an article in the New Zealand Herald, to a school journal story (Hanly, 2003). These physical artefacts, and the classes’ preparation for the 10-year anniversary, were key contributors to the repeat of the unit.

Figure 3. Te Kāuta Menus were Bilingual.



For technology and science, students were divided into three mixed-age groups to explore experiments related to their café, such as mould rates of different breads and insulation materials for hot drinks. This allowed for tuakana-teina, where older students supported younger ones (Winitana, 2012). They conducted blindfolded taste tests and designed fair tests for technological practice, like designing the best containers for keeping food warm and safe ways for the shopping group to transport eggs to school.

After the first day of running the café, the class met to identify areas for improvement. They refined shopping plans based on daily experiences and ultimately made a profit, which the class chose to donate to support building a school in East Timor. One of the workers supporting East Timor’s efforts visited the school to discuss their donation and answer students' questions. She invited students’ input into how they wanted their donation to be spent!

6. CASE STUDY: TE KĀUTA – THE CAF , 2007

When the tuakana (senior) class of 2006 began collating historical materials and scripting a documentary for the immersion unit’s 10th anniversary, the idea of Te Kāuta sparked significant excitement among the students aged 8-11. They requested to run a café themselves, leading to the delivery of a new unit over nine weeks in February and March of 2007. This extensive project integrated various curriculum areas, excluding hākinakina (sport and PE) and puoro (music). Additionally, aspects of teaching and learning would contribute to the 10th-anniversary celebrations in week three of the term. Some outputs of the term, such as tablecloths and uniforms for the waitstaff, were influenced by the 10th-anniversary theme. The class, named after karaka groves, incorporated the karaka motif into their designs. They also produced recycled paper for the menus.

Key differences in the unit's delivery arose due to the junior teacher's focus on the anniversary preparations. The content was adjusted for the older students aged 8-11 (see Figure 4 for a term overview of the learning). The students summarised and synthesised their learning in PowerPoint, making the learning and its corresponding disciplines explicit (see Figure 5 for a sample slide).

Figure 4. Term Overview, 2007.

Overview Term 1 2007 Rm 10, Tuakana Rumaki [Immersion Seniors]

Wāhanga ako [Learning Areas]	Wk 1 (3 days)	Wk 2	Wk 3 10 yr	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8 Te Kauta	Wk 9
Puoro [Music]	Practice bracket + compositions for 10 year celebration								
Hauora [Health]	Sugar / Types	Taste buds / food labelling		Fast foods	Additives / GE	Food pyramid	Design a balanced menu for the café		
Pūtaiao [Science]	Digestion system →			Recycling / Composting systems for café			Shopping / food preparation		
Hangarau [Technology]	Radio – what's the content? Who's the content for? Interviews/ talkshows/ skits			Insulation / packaging / storage / breakage Songwriting – structure/ sequence / Jingles – word play exercises / ads – techniques.					
Tikanga-ā-iwi [Social Studies]	Video 'Day in the life of a café'	Prepare pātai for café visit	Café visit	Feedback on trip	Write own tikanga / systems for running café including hygiene				
Māra [Gardening]	Huaporaka [tadpoles] / harvest potatoes + store / seedlings out / Drying tomatoes / basil			Comfrey / feed soil / Set up worm farm. Harvest kūmara [sweet potato]. Paint pots, worm juice.					Plant out karaka
Momo Tuhi [Writing]	Instructional – Explanation of digestion system / Rātaka [journal entries]			Advertising posters		Menu for café	Instructional - Recipes / tohutohu [instructional and procedural text]		Recount in sections of café
Pāngarau [Maths]	Tauanga [Statistics] for Kauta. Survey designed and data collated.		Tau [Number] →				Money		Ōrau [Percentages]
Toi [Art]	Screenprint tablecloths	Design uniforms	Make + screenprint	Recycled paper / clay plates		Harakeke rourou/table mats	Design table centres		
Te Reo Kōrero [Oral language]	Nikora (1x hour weekly te reo Māori wetewete i te reo) →								
Te Reo Pānui [Reading]	Guided / shared			S.S.R. / Ability groups + ngohe					
Te Reo Ataata [Visual language]				Menus / advertising posters / flyers					
Hākinakina [Sport]	Kauhoe Play/ability groups	Teaching swimming	→			Small balls Padder tennis / Hockey			
Schoolwide	Tau aromatawai Tuhituhi Māori →		~~10 tau~~ celebration	PAT testing				Te Kauta	→

In pāngarau (maths), students collected surveys from the wider school to graph data about favorite foods, drinks, music, and costs. They learned about money measurement, demand and supply, profit, capital, and percentages related to Te Kāuta's costs (see Figure 6). Food was priced to cover costs, and they measured capacity and volume for cooking, often quadrupling quantities.

Figure 5. Slideshow Small-group Plenary.

In pūtaiao (science), they studied the digestive system, composting, worm farming, and recycling systems to choose the best resources for the kāuta. They also cooked and stored food consistently for nearly three weeks. From the school garden, they harvested tomatoes, apples, pears, peaches, grapes, urenika, and potatoes, which they preserved through drying, bottling, and freezing for use in the café.

In tikanga-ā-iwi (social studies), they visited a café to learn about necessary systems and then established their own tikanga and systems for running their café. They practiced roles of hosting, ringa wera (service), and manaaki (hospitality), testing their group roles and relationships to the maximum.

This journey required letting go of routines and structures to learn in new ways, and the children rose to the challenge. The success of the project was supported by the whānau (families), who provided resources, time, and skills, as well as the Māori whānau staff, the wider school's staff, and the tamariki (children) of the class. The collective faith, hard work, and energy in making Te Kāuta a success showcased the power of integrated learning and collaboration.

Figure 7. Bilingual Menu, 2007.

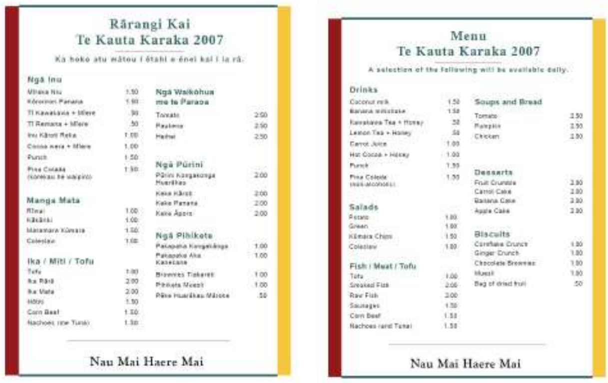
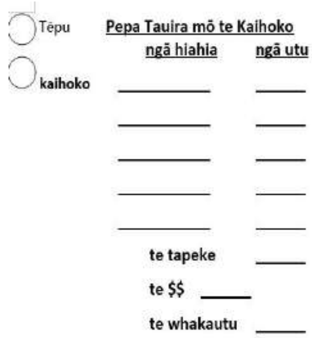


Figure 6. Using Number Knowledge When Taking Orders.



7. DISCUSSION

The two units, delivered in 1999 and 2007, illustrate the evolution of curriculum integration in Māori-medium education. Both successfully incorporated multiple disciplines, engaging students in meaningful, hands-on learning experiences. The fundamental principles of integrated curriculum—using a central organising theme and inquiry-based learning—were consistently applied, demonstrating the enduring relevance of these approaches.

The integrated curriculum effectively met educational goals, with students demonstrating significant engagement and skill development across disciplines. Real-world applications, like running a café, provided relevance and enhanced outcomes. The project-based approach fostered collaboration, critical thinking, and problem-solving.

The findings highlight the potential of integrated curriculum approaches, especially in culturally responsive educational settings. Educators are encouraged to adopt similar strategies, emphasising real-world applications, community involvement, and cultural relevance. The success of these units provides a model for future curriculum design, promoting flexibility, collaboration, and contextual learning.

The practical outcomes of the units align with theoretical frameworks discussed in the literature review, like Jacobs' (1989) model for integrated curricula and Rennie et al.'s (2012) attributes for successful STEM integration. The incorporation of Kaupapa Māori principles further supports culturally grounded practices and Te Kāuta exemplifies the principles for planning curriculum integration identified by Hanly and Lemon (2023).

- Integration should be meaningful and not forced. Each subject area must retain its distinctiveness, with explicit focus times for each discipline, ensuring students understand how the subjects interrelate yet remain distinct. This ensures that students engage deeply with each subject while also appreciating the interconnectedness in real-world applications. In the café project, separate periods were dedicated to learning about health (e.g., karakia kai and understanding sugar consumption), mathematics (e.g., survey creation and data analysis), and technology (e.g., conducting experiments like insulation tests). The integration was purposeful, driven by authentic tasks relevant to the café project.
- Mixed-ability groups foster scaffolded learning through the Māori pedagogical approach of tuakana-teina (Pere, 1982; Tangaere, 1997; Winitana, 2012), where more experienced students (tuakana) guide novices (teina) in their learning. In the café project, this approach was vital, as students from different age groups worked together, sharing responsibilities and learning from one another in a real-world context.
- Explicit teaching of research skills supports student inquiry. Research skills, such as note-taking, data collection, and analysis, should be intentionally modelled and practiced throughout the unit. These skills are crucial for fostering critical thinking and inquiry, especially for younger or pre-literate students. In the café unit, time was set aside to teach students how to design surveys, gather data, and document their findings, ensuring that students developed foundational research skills while exploring real-world problems related to running a café.
- Community involvement enriches the learning experience. Engaging with whānau (families) and community members brings real-world expertise into the classroom, making learning more relevant and meaningful. In the café project, mothers taught traditional weaving techniques, and local café owners shared their professional experiences, offering students both cultural and practical insights. This collaborative engagement deepens students' understanding of the subject matter and enhances their connection to their community, fostering cultural responsiveness and real-world application.

- Culminating activities increase engagement and reinforce learning. Concluding the learning process with a hands-on, community-centred event, like running a café or holding a showcase, motivates students and provides an opportunity to demonstrate their learning. The café unit culminated in a week of running the café, allowing students to apply their skills, receive feedback, and engage with the wider community. This kind of culminating activity not only reinforces learning but also boosts student confidence and provides tangible outcomes for their efforts.

8. CONCLUSION

The café projects from 1999 and 2007 exemplify the effectiveness of key principles such as meaningful integration, explicit discipline distinctions, scaffolded learning through mixed-ability groups, community involvement, and culminating activities. When applied thoughtfully, these principles create engaging and comprehensive learning experiences and foster a more inclusive, culturally responsive, and academically enriching environment for students. The success of these integrated units demonstrates the potential of culturally grounded approaches like Hangarau to enhance learning outcomes and student engagement, particularly in Māori-medium educational contexts.

These case studies provide important insights for curriculum development and policymaking in Aotearoa New Zealand. As we move forward, it is crucial to reflect on how we approach curriculum integration and develop professional practices as a collective. This requires a commitment to continuous learning and the sharing of best practices, ensuring that educators are well-equipped to implement integrated learning that resonates with both cultural and academic goals.

Further case studies are needed to deepen our understanding of how curriculum integration can be most effectively implemented across various contexts, particularly in Indigenous education. These practical examples will help shape policies that are academically rigorous and culturally relevant and sustainable. Opportunities for co-planning and co-teaching with experts, such as those in the Mātanga project (Reinsfield & Fox-Turnbull, 2021), should be expanded, allowing for a more collaborative approach to curriculum design.

Systematic research to measure the impact of integrated learning on students' academic and cultural development is essential. Such research will help educators refine their approach to curriculum integration, ensuring that students gain in-depth knowledge in specific learning areas and an understanding of how these areas connect in real-world scenarios.

By embracing these principles and engaging in ongoing research, educators can make significant strides in advancing curriculum integration in Aotearoa New Zealand. This will benefit students by fostering holistic learning experiences and enrich the wider educational community by promoting collaborative, culturally attuned educational practices.

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Curriculum Integration: Matariki – The Māori New Year

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Abstract

Curriculum integration is popular but challenging for both the teacher and the student when reflecting on the learning and the process of coming to know. This is the third paper in a series. A case study was selected from within a much larger dataset of teaching artefacts, that had been used in English-medium and Māori-medium teaching contexts for year one to eight students in Aotearoa New Zealand (aged between 5 and 12 years). The selected case study representing ten weeks of learning for composite classes of students was then analysed in relation to the literature on curriculum integration utilising an autoethnographic-inspired lens.

The selected case study, entitled Matariki – The Māori New Year, has been repeated annually since 1996, long before this celebration gained popularity on a national level. It is vital with units that repeat frequently, to look for an angle – will the teaching and learning focus on the preservation and storage of food? Or digital storying and re-telling of Matariki stories? What will the culminating event look like and how will whānau and wider community be involved? The planning and classroom delivery of this integrated unit over many iterations is summarised. Then this research builds on emerging principles for effective curriculum integration introduced in the first paper of this series.

Key Words: curriculum integration, Māori-medium technology, Hangarau, autoethography. Matariki, Māori New Year

1. HE WHAKATAKINGA: INTRODUCTION

Curriculum integration presents both opportunities and challenges for teachers and students. For educators, it offers a dynamic way to teach interconnected knowledge, fostering deeper understanding and relevance across subjects. However, it requires meticulous planning, a deep understanding of multiple content areas, and the ability to link these coherently. For students, while curriculum integration can make learning more engaging and applicable to real-world contexts, it can also be complex, demanding higher cognitive integration of diverse concepts. Additionally, the success of such an approach depends significantly on the alignment of educational goals with effective instructional strategies and sufficient resources.

This is the third paper in a series that examines curriculum integration within primary and intermediate sectors in Aotearoa New Zealand, encompassing children aged 5 to 12 years. The series explores the application of The New Zealand Curriculum (Ministry of Education, 2017b) and Te Marautanga o Aotearoa (Ministry of Education, 2017a), the principal frameworks for English-medium and Māori-medium education, respectively. The central inquiry of this paper investigates how planning can purposefully integrate across curriculum areas, beginning with a need or opportunity in Hangarau (Māori-medium Technology). Additionally, this paper considers how to maintain student engagement in annual educational events like Matariki, exploring diverse thematic angles to sustain interest and enhance learning outcomes.

The methodology will be briefly summarised – an autoethnographic-inspired approach (Drawson et al., 2017; Whitinui, 2014) and the method outlined. The focus in the literature review is on the general literature related to curriculum integration and the importance of language acquisition in Māori-medium educational contexts. Selected iterations of Matariki units will be summarised and analysed in relation to the literature, in further refining a set of initial principles for curriculum integration – in the classroom context. We have selected this as a series of units demonstrating purposeful curriculum integration while ensuring that there is significant variation in the learning.

There can be a tendency with annual events, to cover the event in similar ways. It is vital that this doesn't happen, so our next generations' love of learning is fostered and encouraged. Tamsin Hanly, as lead teacher and Ruth Lemon, as kaiārahi i te reo [classroom assistant and language mentor], parent and then teacher – reflect on the units.

2. METHODOLOGY

Table 1.
Ko wai māua? Nō hea māua? Who are we? Where are we from?

Ko Aīrihi, ko Ingarangi ngā iwi. Ko Ngāti Pākehā te hapū. Nō Aotearoa ahau. Ko Tamsin taku ingoa.	I belong to the Irish and English peoples. The Pākehā people are my extended family, those who settled in NZ. I am from Aotearoa NZ. Tamsin is my name. My journey was fruitful, from being a parent who wanted my children

He haerenga whai kiko tōku, mai i te mātua whai pānga ki te reo Māori mō aku tamariki, ki te kaiako arataki i tēnei ruma ako. Kua whakapono au he mea nui kia ārahitia te kaupapa Māori e te Māori, mā te Māori, mō te Māori. Nā reira, ia tau, ka tono au i te whānau kia whakaae rānei kia haere tonu au hei kaiako i tō tātou whānau rumaki reo. He honore nui mōku te mahi ngātahi me te whānau, ā, kua panoni tōku oranga.	to speak te reo Māori, to becoming a teacher in the classroom I believe it is fundamentally important that Māori people lead Kaupapa Māori ventures (like the immersion classroom). Therefore, every year that I taught, I would formally request parents' permission to continue in the role, or to step down so that a Māori teacher would be able to teach. I was honoured to work with the whānau, and it changed my life.
Nō Ngāpuhi, nō Ngāti Pākehā. Ko Ruth taku ingoa. He ara pūmau tōku, i titiro atu au ki tōku whaea e mahi ana, he kaiako kura tuarua, i ōna rā katoa e pukumahi ana, ā, i whakapae au kāore au e whai i taua huarahi. Engari, i huri taku whakaaro i te wā i aru au i tāku tamāhine ki te kōhanga reo. I reira, i kitea e au te koa o te tūhono i ngā whakaaro mā ngā tamariki, te tūhura i ngā ako ngātahi. He honore nui mōku te mahi tahi me te whānau, ā, kua rerekē tōku oranga i tēnei mahi. Tēnā koutou, tēnā koutou, tēnā tātou katoa.	I am Ngāpuhi and European. Ruth is my name. I was certain, watching my mum work hard, as a secondary school teacher, that I would never become a teacher. But following my daughter into a Māori-medium early childhood centre changed my mind. There I found the joy of supporting children in connecting ideas as we explored new learning. I was honoured to work with the whānau, and it changed my life. Greetings to you all, greetings to us together as we engage in this paper together.

Our journey to writing these case studies began in higher education, where we worked together teaching student teachers at Te Puna Wānanga – The School of Māori and Indigenous Education at the University of Auckland. Throughout our teaching, we frequently explored strategies to enhance student teachers' understanding of te ao Māori, which we believe should be the foundation of all teaching and learning. We began informally sharing case studies with our students to help them make connections between theoretical knowledge and practical application. One of our 'noticings' with the student teachers, was that they needed strong scaffolding to develop in their ability to plan for possible angles into a theme. Matariki, the Māori New Year, could only be explored astronomically (although it should also be noted that the breadth of learning in this one area could become the basis for rich and varied learning across years). We wanted them to see that this was one angle, but that there were many other possibilities: from a social sciences' focus on colonisation to a science and technology focus on food preservation.

The goals of this paper are twofold: to refine principles of best practice in curriculum integration and to further the discussion on how these principles can be practically implemented in classrooms.

3. METHOD

This research utilises an autoethnographic-inspired perspective (DeLorme, 2018; McIvor, 2010; Stewart, 2024; Whitinui, 2014), coupled with documentary analysis (McCulloch, 2011; Scott, 1990) to examine a series of teaching resources, including plans, student artefacts, and modelled and shared classroom artefacts. The available dataset represents 25 years of teaching practice across English-medium and Māori-medium contexts with year one to eight students (aged between 5 and 12 years of age). The available dataset consisted of many different document types, including teacher-generated, student-generated, and whole-class generated artefacts. The dataset was scanned for the purpose of this study, this paper being the third paper examining the dataset, refining the initial principles of best practice, with a focus on Māori-medium educational contexts. Matariki, the Māori New Year, was selected as a third case study, because this is an annual event celebrated nationwide now, and we wish to emphasise the diverse ways that Hangarau (Māori-medium Technology) can function as a robust means of planning for integrated learning across the curriculum. The artefacts for the selected unit of learning support the refinement of initial principles for best practice.

4. LITERATURE: CURRICULUM INTEGRATION

There has been a growing interest in curriculum integration within primary school contexts, and this paper will focus particularly on New Zealand research. Using a central organising theme can enhance student engagement and learning outcomes (Dahl, 2019; Hardie et al., 2022; Jacobs, 1989; Moss & Godinho, 2019). For instance, Hardie et al. (2022) highlight the effectiveness of an integrated curriculum approach in fostering entrepreneurship education in New Zealand primary and secondary schools, emphasising that an integrated curriculum reflects the connections between various subjects, enabling students to apply knowledge across disciplines to solve problems and innovate.

The concept of knowledge-rich teaching, as discussed by Rata (2019), emphasises the importance of integrating knowledge across subjects to create a cohesive learning experience for students, suggesting that a well-structured curriculum incorporating a central theme can significantly enhance the learning experience by providing students with a more meaningful context for their studies. Te Marautanga o Aotearoa, the national Māori-medium school curriculum, is grounded in mātauranga Māori (Māori knowledge) reflecting the cultural identity and values of Māori students, thereby enhancing their engagement and success in the educational system (Stewart, 2020).

Recent research underscores the significance of curriculum integration in primary education, particularly in the New Zealand context. The use of a central organising theme enhances student engagement and fosters a deeper understanding of interconnected knowledge across various subjects. By incorporating Māori perspectives and focusing on integrated approaches, educators can create a more inclusive and effective learning environment for all students.

5. CASE STUDY: MATARIKI, THE MĀORI NEW YEAR

When planning the first Matariki unit, there was minimal public knowledge about the Māori New Year, and its significance was not yet widely recognised. To craft an authentic and culturally grounded celebration, the lead teacher collaborated closely with parents, drawing upon their knowledge and community input. Open communication with whānau was essential in shaping the curriculum and gathering resources.

Figure 1. Student Working in the Permaculture Garden

For instance, parents played a key role in providing cultural insights, suggesting relevant readings such as Batten (1995), which informed the integration of both environmental stewardship and cultural practices into the curriculum. Students' learning was then closely tied to sustainable gardening practices through the establishment of a permaculture garden, which allowed them to reconnect with the land while learning about the seasonal cycles that Matariki celebrates (see Figure 1).

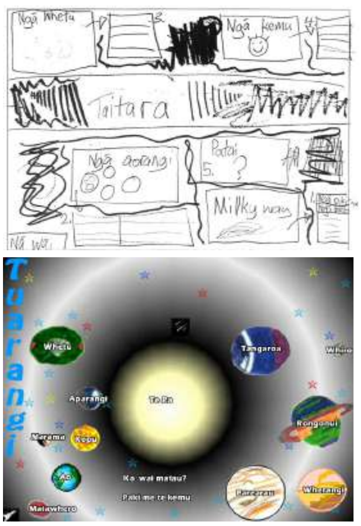
This holistic approach also included lessons on astronomy, where students explored Māori celestial knowledge alongside modern scientific perspectives, gaining both language skills and a deeper scientific understanding of the universe (see Figure 2). The practical aspects of this research-oriented approach allowed students to bridge traditional and contemporary knowledge, enriching both their academic and cultural learning.

The Matariki units have been carefully designed to provide students with a holistic educational experience that emphasises a deep connection to their environment, culture, and community. Each learning outcome of the units is integrated into a framework that encourages environmental stewardship, cultural appreciation, and community engagement. When the units were first being researched, there was minimal knowledge about Matariki in the public domain. The first unit needed parents' input, where they contributed their thinking, and the lead teacher worked on sourcing written information, such as Batten (1995). Open and clear lines of communication with parents are essential in this process.

Students begin their journey by reconnecting with the environment through hands-on activities such as participating in the permaculture organic garden that they had just established at the school. This initiative teaches them about sustainable interactions with the land and ties into lessons on how ecological cycles are observed and celebrated in Māori culture. The gardening activities serve as a practical application of the students' learning about the seasons and traditional Māori seasonal markers.

Figure 2. Student Creating a Representation of the Matariki Stars in Preparation of Our End-of-term Celebration.

Figure 3. Website Design Sharing New Astronomical Knowledge



Knowledge of astronomy is expanded as students explore the universe, solar system, and stars, with a particular focus on celestial bodies significant to Matariki. This astronomical perspective is enriched with Māori vocabulary and concepts, providing students with both language skills and scientific understanding (see Figures 3 and 4). The lessons offer students a comprehensive view of their world and its rhythms.

Figure 4. 3D construction, Representations of Matariki Stars.

Community and whānau engagement are a critical component of the Matariki units. Students participate in Matariki celebrations that involve local community members and families, engaging in rituals that strengthen communal bonds. These activities not only foster a sense of belonging and collective identity but also serve as practical applications of the students' learning about Māori rituals and the significance of community in Māori culture.

Furthermore, the unit challenges students to extend the context in which kaupapa Māori exists. Through discussions and projects, students explore how Māori principles and practices are relevant and can be expressed in broader societal contexts. The curriculum also offers alternatives to Western celebrations, time markers, and calendars. By focusing on Matariki and other Māori events that follow the Māori calendar, the unit provides a culturally rich alternative to the Gregorian calendar, emphasising the cyclical nature of time and the importance of seasonal awareness in Māori culture. See Table 2 for a summary of two selected angles.

Table 2.
Matariki Unit: Two Selected Angles

Core integrating concept	Subjects
Te Wā Matariki me Ngā Peka o te Tau – Time and Seasons  	*Technology:* Manu aute (traditional kite), or hue (a calabash or gourd). The development and reclamation of ritual knowledge around Matariki.
	Maths: Time 24-hour cycles, night and say, annual cycles and seasons, calendars – Māori, Pacific, southern hemisphere, European.
	Science: Tides – the moon and phases of the moon, astronomy, planet studies, planetary orbit, seasons and the maramataka (Māori calendars).
	Social Studies: Matariki star cluster, arrival, sighting, significance – impact of colonisation on this knowledge. Work related to the seasons, agricultural, fishing, planting, harvesting, kūmara cycle and storage, trapping, seed storage. Hine nui te pō (caretaker of the domain of death and dying), grieving customs and practices.
	Health and Literacy: Farewells to those who have passed, goals and goal-writing for the upcoming year.
	Drama/Dance: Changing seasons whakaari (seasonal drama performed at the end-of-term celebration).
	Music: Rhythm, recorder, percussion – composition of music for whakaari.
	Visual Arts: Flowers, fauna, fish, birds of the season. Fibres and fabrics, dyeing of costumes for the whakaari.
Te Rokiroki Kai – Food Preservation  	*Technology:* Small-group projects on food preservation, shared at the end-of-term celebration.
	Science: Heat transfer, food preservation techniques like bottling, drying, smoking, preservation of birds in hinu (grease).
	Social Studies: Time, change, roles and responsibilities. Tikanga or rituals, ceremonies and place-based customs associated with Matariki. Historical approaches to food preservation.
	Health: Māori practices, with a focus on mahi māra (gardening).
	Maths: Measurement, geometry and maramataka (Māori calendar and timings for planting, harvesting to be most efficient with food preservation over the winter months), fractions, proportions and ratios relating to work in science and technology.
	Literacy: Procedural writing of the experiments, and to share finalised processes for the food preservation projects.
	Drama: Shadow puppets, – re-telling the stories learnt through social studies and health.
	Visual arts: Tāniko (finger weaving), raranga (weaving) representations of atua ('gods' or caretakers of a range of domains) and planets, stars to be exhibited at the end-of-term celebration.

If the focus changed slightly, to preparing for a school concert, there could be a strong technology and literacy foundation to learning, where students are scripting, filming and editing a documentary about their concert. If the angle was changed to focus on technology, health and the arts, Matariki is a valuable context for exploring: the creation stories; origins of Māori instruments, the human body and body systems. Sustainable futures and global change could be an angle into this context through a technology, science and social studies lens. Education Outside the Classroom could provide opportunities for children to engage with science learning at the local observatory, or arts and technology at a Matariki exhibition at the local library, gallery or museum. The end-of-term celebration gives students the opportunity to showcase their learning together with parents and wider community (see Figure 5).

Overall, the Matariki units provide an integrated, multidisciplinary learning experience that not only educates but also transforms students' understanding of their place in the world. It encourages them to see the world through a lens that honours their heritage and the environment, fostering a generation that is both knowledgeable and respectful of their culture and the natural world.

Figure 5. Planting Trees, a Whole-School Celebration

Figure 6. Making a Shadow Puppet to Represent a Comet for a School Concert and Recording the Process in a Documentary.

Figure 7. Sending Farewells out to Sea and a Performance About the Seasons

6. CONCLUSIONS AND REFINED PRINCIPLES OF CURRICULUM INTEGRATION

The Matariki units, delivered over several years, showcase the evolution of curriculum integration practices within Māori-medium education, centring on cultural responsiveness and multidisciplinary learning. These units provided students with meaningful, hands-on experiences focused on Matariki, the Māori New Year, effectively employing Fogarty's (2009) curriculum integration models. Notably, the Webbed Model integrated natural and obvious themes, such as celestial observations and Māori rituals, into the fabric of various disciplines. The Threaded Model enhanced learning with cross-disciplinary cognitive tools and strategies. The Integrated Model facilitated interdisciplinary planning, and the Immersed Model connected students' past experiences and prior knowledge with new information about Matariki.

These units met educational goals effectively, with students demonstrating substantial engagement and skill development across disciplines. Real-world applications, including star observation and traditional food preparation, provided contextual relevance, enhancing learning outcomes. The project-based nature of these units fostered collaboration, critical thinking, and problem-solving skills.

The success of the Matariki units highlights the potential of integrated curriculum approaches in culturally relevant settings. Educators are encouraged to adopt similar strategies that emphasise real-world applications, community involvement, and cultural connections. This model advocates for flexibility, collaboration, and contextual learning within and beyond Māori-medium educational settings.

The practical outcomes of the Matariki units align well with the theoretical frameworks proposed by Fraser (2013) and Fogarty (2009). The integration of Kaupapa Māori principles into these units supports the notion that culturally grounded educational approaches can significantly enhance learning experiences.

Specific strategies from the Matariki units that exemplify these principles include:

- Meaningful Integration: Each discipline, such as astronomy, environmental science, and cultural studies, received focused attention, enabling students to distinguish between different areas of learning. This aligns with Fogarty's model, which advocates for integrated learning that connects various disciplines through targeted exploration.
- Tuakana-Teina: Mixed-ability groupings facilitated a Māori pedagogical approach where more experienced students (tuakana) guided less experienced ones (teina), promoting scaffolded learning.

- Explicit Teaching of Research Skills: Students learned to gather and analyse data, such as observing celestial patterns or surveying community knowledge on Matariki, thus enhancing their research capabilities.
- Community Involvement: The units involved whānau and community members extensively in activities like shared meals, storytelling, and traditional Māori crafts, enriching the learning experience and strengthening community bonds.
- Culminating Activities: Each unit built towards a significant Matariki celebration, allowing students to showcase their learning and engage deeply with their community, thereby reinforcing their skills and knowledge through practical application.

In summary, the Matariki units not only adhere to established educational theories but also innovatively apply these in a culturally enriching framework, demonstrating the profound impact of integrating cultural heritage and academic learning.

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Technology and Engineering Education: Project Approach in Learnings

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Abstract

With the initiative of promoting Technology and Engineering Education in our nation, educators are looking for an appropriate pedagogical approach to implementing the said education. In this article, we are investigating the use of "Project Approach in Learnings for STEM Education (STEM PALs)" in deploying technology and engineering education. Since STEM PALs define the framework of a project, spell out the essential elements within a project, explain the details of a 3-act lesson arrangement, and give direction of instruction strategies, it emphasizes the learning effectiveness and altitudes of learners instead of merely knowledge transfer. Various projects as examples of STEM PALs will be given.

Key Words :STEM Education, Project Learning, STEMaker, STEM PALs

1. STEM PALS

With the establishment of the UNESCO Chair in Technology and Engineering Education for Children and Youth in Nanjing on December 9, 2023, a new landscape for children and youth education around the globe was gradually formed. Including Hong Kong, our nation put huge effort into implementing engineering education in our foundation education, that is the K-12 schooling. STEM education will play a more important role in our education, as it is the existing element in our education system related to technology and engineering education. Moreover, Technology(T) and Engineering(E) are the main components within STEM. The features of technology and engineering on the other hand characterize the way of delivery and pedagogy of STEM education.

Last year, one of the authors was awarded the Chief Executive's Award for Teaching Excellence due to their advocacy of the "Project Approach in Learnings for STEM Education (STEM PALs)". In this paper, we investigate how STEM PALs can be applied in Technology and Engineering Education.

1.1. Project Approach in Learnings for STEM Education (STEM PALs)

1.1.1. Definition

Hong Kong's Education Bureau first proposed the implementation of STEM education in 2015, with documents clearly stating that STEM aims "to strengthen the ability of students to integrate and apply their knowledge and skills across different subject disciplines through solving daily life problems with practical solutions and innovative designs." This indicates the necessity of hands-on learning in STEM education. For foundational education, hands-on practice is also the core of technology and engineering education. The most effective and easiest-to-understood learning model is through well-defined projects.

A project generally refers to a plan with specific purposes, temporary or short-term, and capable of gradual improvement. Learning through projects hence can be referred to as the "Project Approach in Learnings."

1.1.2. Mutual Influences of TE and STEM

The project approach aligns with the key features of both Technology Education (TE) and STEM education. One critical aspect of engineering education is the "iterative design process" (Paul & Roger, Critical Features of Engineering Design in Technology Education), which emphasizes collaborative learning environments. In this context, students are encouraged to communicate, share ideas, and work as teams on project tasks, which closely aligns with STEM practices.

Conversely, to successfully complete these projects, students intentionally learn and utilize a variety of technological tools, including basic, modern, and digital technologies. Since technology and engineering are grounded in scientific principles, students inevitably apply knowledge from mathematics and science to solve design problems. By connecting classroom learning to industry practices and societal needs, educators can enhance student motivation and engagement, making learning more meaningful and relevant.

1.1.3. Characteristics of the Project Approach in Learnings PALs

In normal school context, with 30-50 minutes a lesson, and several subjects of different lessons in a school day. It is impossible to carry and finish a project with consecutive lessons. The Project Approach in Learning PALs involves breaking down a project into several parts, completed through a series of lessons. The entire process aims at problem-solving, allowing students to learn knowledge that might not be pre-arranged, even across different subjects. PALs accommodates different learning paces and tolerate existing learning differences, suitable for catering students with learning diversity. Students take a more proactive role in seeking knowledge through doing projects. PALs framework is more complex and flexible than ordinary lessons, handling each lesson according to specific progress and requiring adaptability. We believe that with PALs, hands-on learning can nurture high order thinking of students. In order to achieve this goal, we need to take close look on how PALs works, and eventually, we formulate three important elements of PALs, they are "Project Planning," "Lesson Arrangement," and "Instruction Strategy."

2. PROJECT PLANNING

Technology and engineering education, along with STEM education, no longer follow a topic-based one-lesson-at-a-time approach but instead enhance students' observation and empathy by finding and solving problems in real-life authentic scenarios. The entire process follows a design cycle. To develop a high-quality curriculum, it is essential to formulate high quality projects. PALs provides clear guidance, listing out five essential elements in project planning. They are Problem-Based, Scenario Leading, Knowledge Connectedness, Exploration and Elaboration and Tangible Production.

(i) Problem-Based: STEM education thrives on problem-solving projects, where identifying and addressing real-world problems is key. In the Project Approach in Learnings (PALs), problems should be discovered by students rather than predefined by teachers. This student-driven discovery can be facilitated using the "Five Rings of Problems" approach: needs, accidents, current situations, difficulties, and challenges. Unlike traditional methods, PALs projects are based on ill-defined problems within specific scenarios, encouraging students to explore and innovate. For instance, in a Grade 8 project, students might design a device to address the inconvenience of charging a mobile phone while using it. They would research materials, analyse designs, and develop solutions, thereby enhancing their problem-solving skills. Another example involves Grade 8 students creating a solar-powered wind boat to address transportation issues in a future water world scenario, integrating principles of Newtonian mechanics and buoyancy. Such problem-based projects foster self-directed learning and practical application of knowledge.

(ii) Scenario Leading: The source of the problem must be based on a real and authentic situation. PALs must have problems that need to be solved, and problems are often unclear or even hidden. But the situation corresponding to the problem must be real and clear. Authentic scenario is the core of Scenario Leading. The purpose is to allow students to immerse themselves in the scenario and atmosphere to identify problems. Let students integrate into the scenario, feel the difficulties of the users in the scenario with their hearts, and draw empathy and resonance. When designing PALs projects, students’ environment or current social situation should be considered. This can provide greater experience value and make students feel that the scenario is relevant to themself. For example, in a Grade 9 project to create a Bluetooth speaker, students had to think about the speaker's location, user, and purpose, driving them to conduct a series of scenario investigations. The final products were designed and made according to different scenario needs. After all, use the things around students to arouse their curiosity and empathy, and make caring about the things around them a habit.

(iii) Knowledge Connectedness: During teaching, we emphasize the connectedness of subject knowledge, enabling students to apply learned concepts in designing projects. Apart from understanding the required knowledge, we consider students' prior learning progress to connect and apply newly acquired knowledge. For example, in the VR glasses project, students used ray diagrams from physics to determine the distance between the lens and the phone. This approach not only enables successful project completion but also deepens students' learning experience. When planning projects, teachers must understand the project requirements and explore students' learning progress in each subject. The connection of knowledge aims to integrate existing or newly learned knowledge. This approach places high demands on teachers, who need a balanced and broad knowledge background to effectively guide students. Similarly, when teaching Grade 8 students to join acrylic sheets, we guided them to observe the relationships between solutions, solvents, saturated solutions, and crystallization, aligning this knowledge with their science lessons.

(iv) Exploration and Elaboration: The "Exploration" in STEM projects emphasizes hands-on practice with continuous improvement as the goal, enabling students to enhance their experience, skills, and understanding of knowledge. This process drives thinking through practical engagement with tools and materials, leading to active exploration and the use of technology to solve problems. The most effective way to master materials, tools, and equipment is through hands-on practice and exploration. This distinguishes STEM education, as it goes beyond mere knowledge acquisition. For example, in a "Transformable Keychain" project, students experienced the softening of thermoplastic without using instruments, deeply understanding the material's properties through hands-on bending. During problem-solving, in-depth research and repeated verification lead to the best solutions, a unique feature of project-based learning. This continuous improvement process, with diverse methods like experiments and data analysis, is the driving force behind STEM exploration, where personal and true experience is the ultimate goal.

(v) Tangible Production: Our projects involve tangible production, encouraging students to understand the material world through direct contact with materials and present their knowledge and imagination through physical creations. The most fascinating thing about STEM is that there are products that can actually be used to solve problems in an authentic scenario. Despite this, many people still believe that the presentation of STEM can be expressed in the form of pure programming. In recent years, with the rise of artificial intelligence and big data, there are many people who use computer programs purely as the final product. We agree with the importance of this type of work, but it does not mean that these are STEM. In terms of convenience in execution, there is no doubt that the creation of computer programming can save a lot of effort in material use, mechanical operation and equipment maintenance. However, there is no better way to understand the material world than through direct contact with materials. The aforementioned "Exploration and Elaboration", and "Knowledge Connectedness" cannot be simply replaced by the learning experience of computer programming. For example, in a Grade 8 "Campus Beautification Plan" project, the focus was on geometric plane design. Instead of using drawing forms or computer graphics software, we chose wood as the material, allowing students to carve with hand tools, experiencing the joy of material shaping. Now, our campus displays two decorative panels made by different students, who feel proud of their contributions. Having said that, what is the position of computer programming and artificial intelligence in STEM? In fact, it is not unimportant. They are a powerful tool among many tools, but it does not mean that they can replace all tools. We often encourage students to incorporate a large number of electronic control and programming elements into their works to achieve optimal performance. Take the HKCEE public examination project of a Form 5 student many years ago as an example. The topic was originally "Turtle Garden" and had nothing to do with information technology. However, in the end, one of the student's work incorporated a large number of information technology elements to achieve real-time remote control and real-time video transmission. It was already implemented in an era when there was no Internet of Things. Therefore, for "Tangible Production", the product should be "made as you think and used as you plan for". The turtle tank housed a pair of small turtles in a corner of the our workshop over 10 years long.

3. LESSON ARRANGEMENT

3.1. Three-Act Structure of a Lesson

To align with the flexibility and complexity of the Project Approach in Learnings, each lesson is divided into three stages: setup, confrontation, and resolution, allowing students to grasp each lesson's knowledge clearly and systematically.

3.1.1. Setup

The setup stage involves arousing students' interest and establishing the learning goal. This can be achieved through various means such as storytelling, showing relevant videos, or presenting a real-life problem that needs to be solved. The acronym INTRO can be used to remember the key elements:

3.1.1. Setup

The setup stage involves arousing students' interest and establishing the learning goal. This can be achieved through various means such as storytelling, showing relevant videos, or presenting a real-life problem that needs to be solved. The acronym INTRO can be used to remember the key elements:

- Interest: Capture students' attention and curiosity.

  "I" stands for Interest, which arouses students' interest in learning. If students lose interest in class at the beginning, there is no way to get them to re-engage in class. Young teachers always have a wrong expectation, they eager to get applause and gain recognition from the students. However, we should realized that effective teaching require students to be interested in class and learning, instead of the teachers. Bear in mind the escapement technique in thought. It turns out that the escapement technique can be used to arouse students' interest before the beginning of class. Students have already taken several classes of different subjects and have just changed their learning environment to the workshop. At least they are a little relaxed mentally and have lost the original feeling of sitting still in the classroom. It is a bit difficult for students to concentrate immediately as soon as they enter the workshop. Fortunately, we can use physical conditioning to give students some concentration training first. The method is actually very simple and very logical. It is to establish a rule with the students. After entering the workshop every class, they must stand up at the assigned seat. Wait for all students to arrive, salute first, and then sit down. Often in some classes that are more lively and active, or in some classes that have just transferred from a more lively class, students must still be talking or whispering. What the teacher has to do at this time is to look at the students who are making noise. When the students calm down, the teacher's eyes will move to other students who are still making noise. There is no need for the teacher to stop them, the students will understand, and sometimes even the classmates will help the teacher to remind each other. Before saluting, teachers should not forget to respond to the students' quiet cooperation with a smile. It turns out that this is the use of the escapement technique. The relaxed scene when the students transfer to the class is the moment of indulgence. When the students enter the workshop, we must first draw everyone's attention back. So how do you attract interest? We usually use visual cues to arouse students' interest in learning. We try to hope that students will be mentally prepared for the class after saluting and before sitting down. Visual reminders can include pictures or words typed on the screen in advance, physical models of the lesson that have been preset, or experimental equipment placed on students' desks in advance.

- Need: Establish the necessity and relevance of the lesson content.
  "N" stands for Need, that is, demand. The STEM hands-on lesson is like magic, turning each student's design concept into a physical object. During the process, students will learn the use of different tools and materials and will also practice how to achieve design effects through different mechanical structures, electronic circuits, and programming techniques. Therefore, it is most logical to turn the design goals of students' project into learning needs before the start of class. Just like students need to learn Arduino programming in a robotic project, we will ask students to first think about how to make the robot smarter and responsive to the environment, thereby guiding students to understand the need to learn new knowledge in addition to mechanical design in order to achieve for best results. When necessary, pre-made models are even used to explain the difficulties faced by students in their projects, so that students can understand their learning needs. It can be seen from this that STEM teachers need to have a good understanding of individual students' learning and production processes, and try their best to synchronize students' pace of production, so that students can feel that they can apply what they have learned.
- Title: State the title of the lesson.
  "T" stands for Title, which is the name of the lesson. When one of the authors first debuted, he often felt confused when faced with practical lessons. Since students are making and practicing throughout the class, isn't the title of the lesson not only the name of the project? or just put down a simple word "Realization" on the teaching schedule? Later, with more experience, we learned that students often encounter many different problems during hands-on practice. And over and over again, we found that the difficulties encountered by students in the same project can be said to be similar and can be classified. The difficulties encountered by students in a certain type of projects are also the same. So when planning students' project, in addition to subject matching and knowledge connectedness, it should take into account students' hands-on ability and spatial imagination. These considerations gradually developed and became a series of topics in STEM practice. Having said that, being able to clearly indicate the title to students when introducing the lesson will not only make the class objectives clearer, but also indirectly make the entire course planning clearer.
- Revision: Review the progress of last lesson.
  "R" stands for Revision, which means review. In each lesson, the first 5 minutes are used to review the teaching content of the previous lesson with the students. In addition to consolidating the knowledge learned, more importantly, it can continue the project progress of the previous lesson. One of the difficulties in STEM hands-on project is that the time span is long. A project often takes several teaching weeks to complete, making it difficult to complete all the practical tasks in one go. In a complex project production process, the continuation of the project is like the handover of a construction project. Every detail must be coordinated properly. Otherwise, what is produced in each lesson will not be assembled together. In addition to wasting time, it also greatly affects students' self-confidence. Teachers can briefly describe, or ask students with higher abilities to repeat, the topics, content and project progress of the previous lesson.
- Objectives: Provide the objectives of the lesson.
  "O" stands for Objectives, that is, goals. Clear learning goals can give students a clear direction. Following the previous key point of "review", teachers can introduce the scheduled progress of this lesson while reviewing the project progress of the previous lesson, so that students can have a goal to follow. Of course, the learning objectives of the teaching content also need to be explained briefly.

Although it is not too difficult to master the above five I-N-T-R-Os, it does take more practice to complete them within 5 minutes. A course introduction that is too lengthy will put the cart before the horse and make the entire class lose focus.

3.1.2. Confrontation
We divide the lesson into several short teaching blocks according to the basic production steps, each teaching block does not exceed 15 minutes. The differentiation of blocks can help students memorize the steps during the project, and can also be used to demonstrate techniques and skills between teaching blocks, while giving students time to recuperate. Between teaching blocks is a good time for us to help students summarize their experiences and reflect. Some simple introductory hands-on projects can sometimes be shortened to 5 minutes per teaching block. After the explanation between each teaching blocks is completed, it is the student practicing period. In this way, dividing the classroom layer by layer is like peeling an onion, so we call this onion-style lesson confrontation.

3.1.3. Resolution
In a complete lesson, teachers must discuss with students right after the lesson and review the topic of the lesson by asking questions to understand the students' progress and set goals for the next time. Spending 3-5 minutes each lesson period summarizing the lesson with students will have a good learning effect. In addition to summarizing the lesson content, a

complete hands-on practical lesson has to complete the hands-on part, that is, put away students' works and put the used tools back to their original places, and clean the workshop and used places. Waste generated during the process should be properly recycled or disposed of. This can also cultivate the habit of self-discipline and compliance among students. For personal hygiene, students must also clean their hands properly before leaving.

4. INSTRUCTION STRATEGY

Because PALs divides the entire project into multiple discontinuous lessons, due to workshop accommodation issues in Hong Kong, the design and technology subjects at the junior and intermediate levels in our school need to be held in groups every other week, causing problems between lessons. At least half a month's time gap. Therefore, we need to develop some practices in lesson management to maintain continuity between lessons. We referred to the 3Cs proposed by Alister Jones in 2007, and based on the needs of the school, we added one more C and successfully developed a 4C Instruction Strategy: (1) Connectedness of technological elements, which is consistent with the "knowledge connectedness" mentioned in the project planning. We deliberately outline the knowledge connectedness with other subjects in the entire lesson to allow students to have a deeper understanding and apply what they have learned; (2) Coherence of goals, always reminding students that the lesson formed part of the entire project , and explain the position of the lessons in the entire project, and the progress goals it should have; (3) Continuity of the lesson, we will provide after-class extension activities and preview the learning that will be included in the next lesson. The focus is to allow students to continue their learning throughout the lesson; (4) Finally, Convergence is the focus of learning outcomes. We will give students some assessment feedback to enhance learning based on the lesson learning and teaching objectives to ensure that students have a solid knowledge base to cope with the assessment and can master the key points of the lesson.

5. CONCLUSION

The Project Approach in Learnings (PALs) offers a robust framework for integrating technology and engineering education within the broader context of STEM education. By emphasizing problem-based learning, scenario immersion, knowledge connectedness, exploration and elaboration, and tangible production, PALs fosters a hands-on, interdisciplinary approach that enhances students' problem-solving skills and real-world application of knowledge. PALs helps in nurturing high order thinking and self-directed learning as well.

As technology and engineering continue to evolve, the need for adaptive and innovative educational strategies becomes increasingly important. PALs not only addresses this need but also aligns with the global trends in technology and engineering education as well as in STEM education, preparing students to meet future challenges with creativity and resilience. By focusing on authentic problems and encouraging iterative exploration, PALs nurtures a generation of learners who are not only knowledgeable but also capable of critical thinking and innovation.

STEM PALs has been implemented in some schools in Hong Kong, we believe that PALs also is an appropriate approach for technology and engineering education, providing educators with a powerful tool to inspire and equip students for the future. As we continue to refine and implement PALs, STEM PALs and TE PALs, we look forward to seeing their lasting impact on education and society.

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The impact of gender stereotypes on self-efficacy, creative thinking attitude, and project-based learning value in technology and engineering education among Chinese junior high students

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Abstract

Previous research has demonstrated that gender stereotypes associated with girl's gender can obviously deteriorate technology and engineering education (TEE) results. However, it remains unclear whether these stereotypes affect other relevant factors in TEE performance, specifically technology and engineering self-efficacy (TESE), creative thinking attitudes (CTA), and project-based learning value (PBLV). This study used quantitative methods to investigate the correlation between participants' TESE, CTA, and PBLV, moderated by gender stereotypes. A total of 262 junior high school students completed a powered carts project and gender stereotype measures. Correlation analysis showed that dimensions of CTA were positively correlated with PBLV, and TESE was positively correlated with CTA and PBLV. Moreover, gender stereotypes moderated the relationships between the three variables. That is, gender stereotypes can effectively moderate individuals' CTA and TESE in TEE environments based on the project-based learning approach. Therefore, teachers should create an inclusive learning environment, utilizing authentic teaching methods and diverse materials to showcase gender achievements in TEE, thereby highlighting each gender's unique potential in the field. In addition, with early intervention, it is possible to create a more equitable environment to minimize the impact of gender stereotypes on students in TEE.

Key Words: Gender Stereotype · technology and engineering · self-efficacy · creative thinking attitude· project-based learning value

1. INTRODUCTION

Technology and engineering, foundational to STEM education, face gender stereotypes influencing motivation and participation in these fields (Fan et al., 2020; Torkar et al., 2018; McGuire et al., 2020). A significant gender-based interest divergence appears in high school, particularly diminishing girls' interest in technology and engineering (Medawar, 2023). Despite knowing gender stereotypes impact career interests, less research examines these effects in younger students within TEE (Buckley et al., 2023). This study explores gender stereotypes' impact on junior high students' technology and engineering self-efficacy (TESE) within TEE.

Using Bronfenbrenner's micro-ecological system model, PPCM (Bronfenbrenner, 1979), this study views "person" as cognitive-emotional attributes like TESE, "content" as project-based learning (PBL), and "process" as the PBL's influence on students. Prior research has investigated self-efficacy and disparities in TEE (Rosli & Saleh, 2023), the significance of creative thinking in engineering (Jang, 2016), and PBL's role in fostering creative attitudes (Goldman & Zielezinski, 2022). However, interactions among these elements and how gender stereotypes may moderate such interactions remain underexplored.

Our research investigates the interplay between TESE and creative thinking, and their influence on the value derived from PBL, while focusing on the moderating role of gender stereotypes. This approach is particularly pertinent for female students, aiming to bolster their self-efficacy and creative thinking within TEE via PBL—and thus counteract the underrepresentation of women in technology and engineering by mitigating the societal Pygmalion effect that shapes educational choices and careers.

2.THEORETICAL BACKGROUND

2.1. Technology and engineering self-efficacy

Self-efficacy, the belief in one's abilities, is crucial for engagement and success in specific tasks, significantly affecting work management, career choices, and performance (Bandura, 1995; Schaubroeck & Merritt, 1997). In technology and engineering, those with higher self-efficacy (TESE) are more likely to excel and innovate (Sakellariou & Fang, 2021; Beghetto, 2006). Positive correlations with academic success (Chen, 2017) and TEE attitudes (Compeau & Higgins, 1995; Yeşilyurt et al., 2016) suggest that enhancing TESE could improve learning outcomes.

2.2. Creative Thinking Attitude

Creative thinking is fundamental to generating original solutions (Torrance, 1971; Guilford, 1967) and involves intellectual, emotional, and motivational aspects (Zlate, 1994). Defined as creative thinking attitude (CTA), this disposition to innovate is critical for technology and engineering problem-solving. TEE, which encourages problem identification and solution creation, is known to shape CTA through design production (Liu et al., 2020; Vuletic et al., 2018).

2.3. Project-Based Learning Value

Project-Based Learning value (PBLV) arises from students assigning worth to a learning program, which boosts motivation and self-efficacy (Atkinson, 1957; Beier et al., 2018; Holmes & Hwang, 2016). PBLV's significance in TEE is highlighted by its enhancement of communication and management skills (Dogara et al., 2020), prompting an inquiry into PBLV complexity within TEE education.

2.4. Gender Stereotyping

Gender stereotypes, expectations applied to individuals based on their social grouping, impact self-efficacy and performance (Ellemers, 2018; Kalender et al., 2020). Technological talent, often gender-stereotyped, undermines women's pursuit of technology and engineering careers despite equal or superior abilities (Mascret & Cury, 2015; Kelan, 2007; Mumporeze & Prieler, 2017). The gender gap in TEE begins in childhood and extends into adulthood with fewer women in TEE domains (Cvencek et al., 2011; Riegle-Crumb et al., 2017). Investigating the impact of gender stereotypes on adolescents in technology and engineering is essential for addressing the gender gap and promoting equitable educational environments.

Given the importance of TESE, CTA, PBLV, and gender stereotypes in shaping students' engagement and success in TEE, this study seeks to examine these elements concurrently in a junior high setting. We aim to determine how gender stereotypes moderate the relationships between TESE, CTA, and PBLV, thereby identifying strategies to mitigate the gender gap and enhance the representation of women in technology and engineering. This investigation fills a critical gap in the current understanding and presents an imperative for the research outlined in this article.

3. THE CURRENT STUDY

3.1. Research Hypotheses

The prevalent masculine image of Technology and Engineering Education (TEE) dissuades many girls from pursuing these fields, influenced by societal stereotypes. This research aims to identify strategies to create an inclusive TEE environment for all genders by reassessing teaching methods and emphasizing early intervention to counteract gender stereotypes. It is recognized that boys often perceive themselves as more creative in TEE, which may discourage girls. Research suggests enhancing girls' self-esteem in TEE can reduce the gender gap, with Project-Based Learning (PBL) beneficial for students' creative thinking and self-efficacy. The study examines the interplay between Technology and Engineering Self-Efficacy (TESE), Creative Thinking Attitude (CTA), and PBL, proposing four hypotheses:

H1: Higher TESE is linked to a more positive CTA.

H2: CTA improves with the application of PBL in TEE.

H3: TESE boosts the perceived value of PBL.

H4: Gender stereotyping moderates the effect of CTA on PBL value.

The research deepens understanding of how project-based approaches and self-efficacy impact creativity and the potential of such interventions to combat gender stereotypes in TEE.

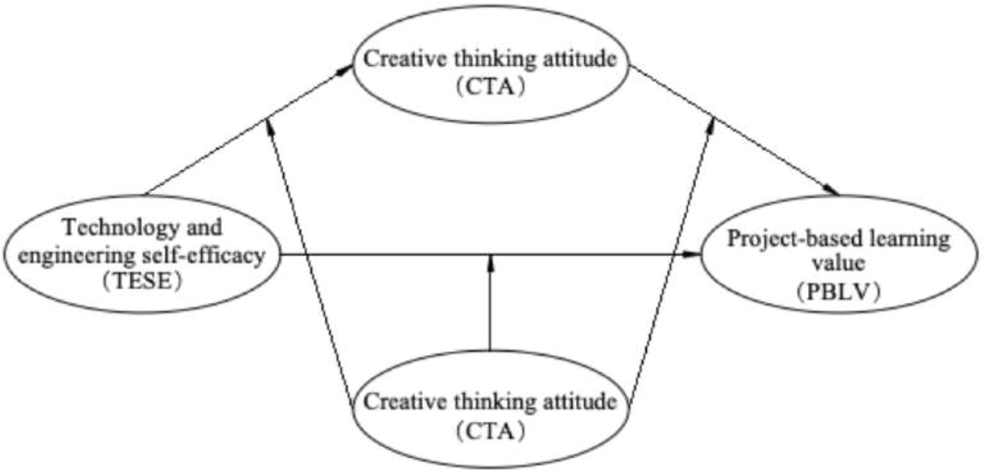
3.2. Research Model

The ecological perspective emphasizes the dynamic interplay between individuals and their environments, showcasing the bidirectional influence of broader and immediate contexts (Bronfenbrenner, 1979; Harvey, 2007). Ecological systems theory, along with the Process-Person-Context model (PPCM), describes an individual's development amid environmental factors (Bronfenbrenner, 1979). These factors encompass Interest, Resource, and Demand, and they affect the proximal process, which could either promote or hinder development.

Environmental variables comprise four systems: the micro-system (immediate surroundings like peers and teachers), meso-system (interactions within the micro-system), exo-system (external contexts), and macro-system (sociocultural structures such as values and culture) (Tudge et al., 2016). In this research, the 'person' represents individual attributes, specifically technology and engineering self-efficacy (TESE), creative thinking attitudes (CTA), and gender stereotypes.

'Context' is the tech and engineering education (TEE) infused with project-based learning, and 'process' denotes the resultant influence on the perceived value of this educational approach, as depicted in Figure 1.

Figure 1.
Research Model



4.METHODOLOGY

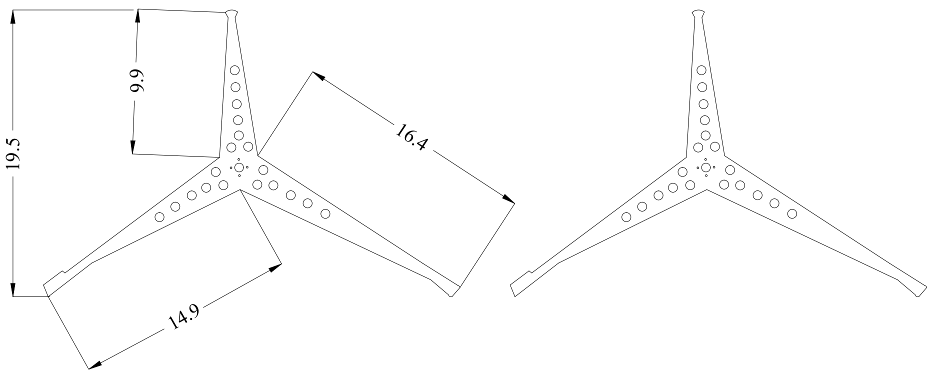
4.1Participants and Data Collection

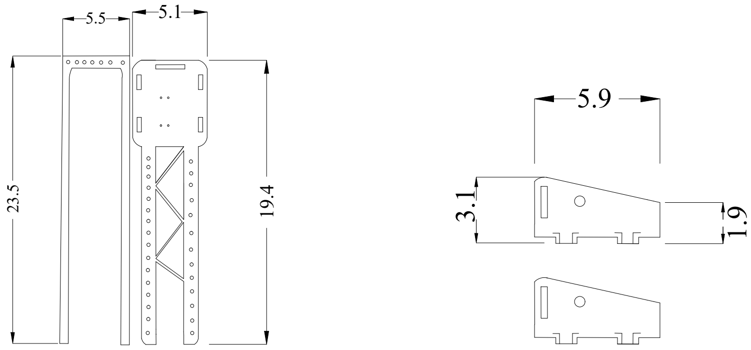
In this study, 315 ninth-grade students from three junior high schools in Nanjing, China, aged between 15 to 17 years, were purposively sampled. Participation was voluntary, with data gathered from May to July 2023, under the School of Psychology Ethics Committee's approval. To ensure ethical standards, consent forms were provided, and confidentiality was strictly upheld. Out of the initially collected 315 questionnaires, only 262 valid responses remained after discarding incomplete ones, adhering to the five to eight observations per parameter rule for confirmatory research (Lemeshow et al., 1990). The sample consisted of 134 males (51.1%) and 128 females (48.9%), with 29.1% aged 15, 43.3% aged 16, and 27.6% aged 17. Participants from towns constituted 40.8%, whereas city-dwellers made up 59.2%.

4.2 Research Setting

The study targeted a specific group of students participating in the "Experiments in Science Space Vehicles of the Future" competition, which challenged them to design and construct a powered cart capable of navigating obstacles within a set time frame. The carts had to meet defined size (no larger than 25cm×25cm×25cm) and weight (under 400g) parameters. This cohort was selected due to the direct relevance of their competitive experience to the assessment of Project-Based Learning value (PBLV). The use of Computer-Aided Design (CAD) in the competition enabled students to produce engineering drawings (refer to Fig. 2), offering a practical measure of their engineering abilities.

Figure 2.
The powered cart parts design of wheel, stent, battery installation, gears (from left to right）





4.3. Survey Instrument

The questionnaire comprised 40 items across four constructs, adapted from established literature and validated through expert review and preliminary testing with junior high students to ensure both face and content validity. Items were structured using a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

The constructs included:

(i) Gender Stereotypes in Technology and Engineering (GSTE): Eight items assessed awareness, endorsement, and flexibility related to gender stereotypes in technology and engineering, modified from Liben and Bigler (2002). An item example is, "I think that female students are not as talented as male students when learning technology and engineering."

(ii) Self-efficacy in Technology and Engineering (SETE): Twelve items measured students' confidence regarding their capabilities in technology and engineering thought processes, production, and persistence, adapted from scales by Bandura (1989) and Lent et al. (1986). Example items include statements about formulating hypotheses and understanding information, confidence in performing tasks, and coping with difficulties in technology and engineering.

(iii) Creative Thinking Attitude in Technology and Engineering (CTATE): Nine items addressed aspects like adventure, curiosity, and imagination within technology and engineering, based on the Marmara Creative Thinking Dispositions Scale (Özgenel & Cetin, 2017). Examples include enjoyment in problem-solving, interest in new information, and persistence in the face of unsolved problems.

(iv) Project-Based Learning in Technology and Engineering (PBLTE): Items explored students' learning desires related to daily life and their willingness to engage in future projects after participating in project-based activities.

5. DATA ANALYSIS

5.1. Questionnaire Item Analyses

First-order confirmatory factor analysis (CFA) was conducted to assess the constructs of PBL, CTA, and TESE concerning item validity, adhering to thresholds suggested by Hair et al. (2019). Items with factor loading values below 0.5 were excluded. Subsequently, the items with the highest residual values within each construct were systematically removed until the CFA criteria were satisfied: chi-square/df < 5, RMSEA < 0.08, GFI > 0.8, and AGFI > 0.8. This process resulted in retaining 11 items for TESE, CTA, and PBL, and seven items for the gender stereotypes variable (Table 1).

Table 1.
Item Analysis

Measurement fit	Threshold value	TESE	CTA	PBLV
x^2/df	<5	.912	1.020	2.148
RMSEA	<0.08	.000	.009	.066
AGFI	0.80	.963	.959	.928
GFI	0.80	.978	.978	.962

Notes: x2/df stands for standards for fit include chi-square/df, RMSEA stands for root mean square error of approximation, GFI stands for goodness-of-fit index, AGFI stands for adjusted goodness-of-fit index. CTA stands for creative thinking attitude, TESE stands for technology and engineering self-efficacy, PBLV stands for project-based learning value.

5.2. Reliability and Validity Analysis

Internal consistency was assessed using composite reliability (CR), with all three constructs exhibiting CR values greater than 0.81, surpassing Hair et al.'s (2019) recommended cutoff of 0.7. Additionally, all Cronbach's alpha values exceeded the criterion of 0.7 set by Kenny et al. (2015), ranging from 0.781 to 0.825. Convergent validity was evaluated using factor loading (FL) and average variance extracted (AVE) values. The results indicated that the AVE values ranged from 0.365 to 0.450, and FL values ranged from 0.450 to 0.9, both within the acceptable thresholds set by Hair et al. (2019).

Table 2.
Reliability and Validity Analyses

Construct	Cronbach's *α*	CR	AVE	FL
TESE	.781	.819	.365	.505~.670
CTA	.815	.893	.466	.469~.892
PBLV	.825	.867	.450	.589~.760

6. RESULTS

6.1. Simply Descriptive of the samples

Among the 11 items evaluated, certain dimensions presented reliability and validity issues. Specifically, one item each from TESE (M=4.053, SD=0.552) and CTA (M=4.069, SD=0.594) showed insufficient reliability and validity, along with two items from PBLV (M=4.019, SD=0.671). Consequently, TESE and CTA now include 10 items each, while PBLV is represented by 9 items, following the exclusion of items not meeting the required standards. Additionally, a correlation matrix analysis of the variables was conducted in line with the study's objectives (refer to Table 3).

Table 3.
Simply descriptive information

Construct	Number of items	Mean	*SD*	Maximum value	Minimum value	TESE	CTA	PBLV
TESE	10	4.052	.552	4.90	1.50	1	--	--
CTA	10	4.069	.594	5.00	1.50	0.415**	1	--
PBLV	9	4.019	.671	4.89	1.44	0.672**	0.634**	1

6.2. Model Fit Analysis

The hypotheses were tested using a structural equation model, with the following fit criteria: chi-square/df < 5, RMSEA < 0.08, GFI > 0.8, and AGFI > 0.8. Additionally, the incremental fit measures, including the non-normal fit index (NNFI), incremental fit index (IFI), and comparative fit index (CFI), required values greater than 0.9. The model's acceptability was confirmed as all fit indices met or exceeded the specified thresholds, as detailed in Table 4.

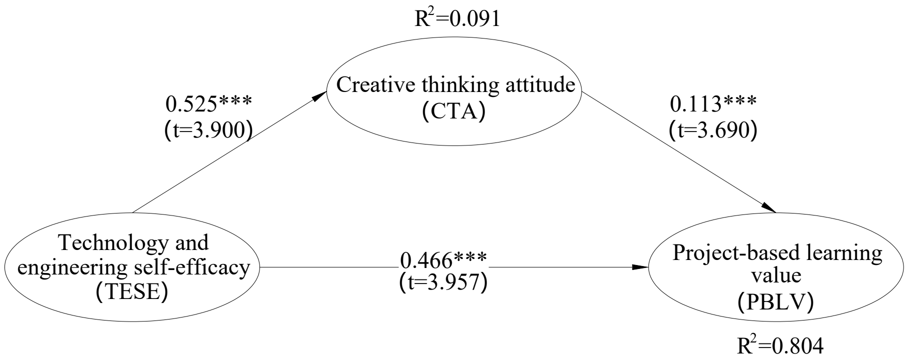
Table 4.
Structural Model Fit Analysis

Index	Threshold	Inspection data	Result
x^2/df	<5	2.130	Support
RMSEA	<0.08	.066	Support
GFI	.80	.813	Support
CFI	.80	.836	Support
TLI	.80	.818	Support
PNFI	.50	.663	Support
PCFI	.50	.755	Support

6.3. Path Analysis

According to Hair et al. (2019), Structural Equation Modeling (SEM) is a widely utilized technique for testing structural hypotheses derived from models. The path connection results in Figure 5 indicate that all hypotheses were supported at a significance level of 0.001. TESE positively predicts both CTA (β = 0.33, t = 5.49, p < 0.001) and PBLV (β = 0.43, t = 8.18, p = 0.001). These results demonstrate that all variables exhibit strong predictive potential, exceeding the suggested threshold value of 10% (Hair et al., 2019).

Figure 5.
Verification of the Research Model

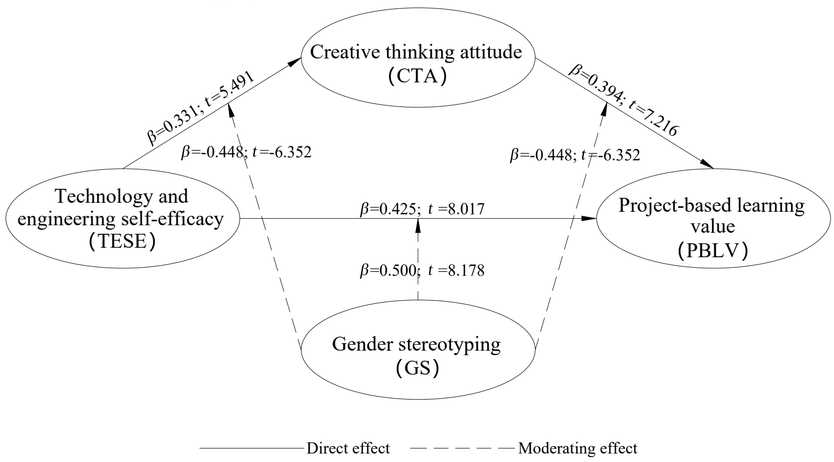


*Note. (***p < .001)*

6.4. The Moderating Role of Gender Stereotyping

Using Model 59 from SPSS MACRO PROCESS version 2.15, a moderated mediation analysis was conducted (Fig. 6). Table 5 shows that gender stereotypes serve as a significant moderating factor. Specifically, gender stereotypes significantly moderated the relationship between TESE and PBLV (β = 0.50; t = 8.18; p < .001). They also moderated the effect of TESE on CTA (β = -0.49; t = -6.35; p < .001) and the impact of CTA on PBLV (β = -0.55; t = -7.58; p < .001). Thus, the relationships among TESE, CTA, and PBLV are significantly influenced by gender stereotypes.

Figure 6.
Moderated-Mediation Role of Gender Stereotyping



*Note. (***p < .001)*

Table 5.
The Coefficients of the Moderated-Mediation Analysis.

	β	SE	95%	
	CTA		LL	UL
GS	.13	.05	.01	.24
TESE GS	-.45****	.07	-.59	-.31

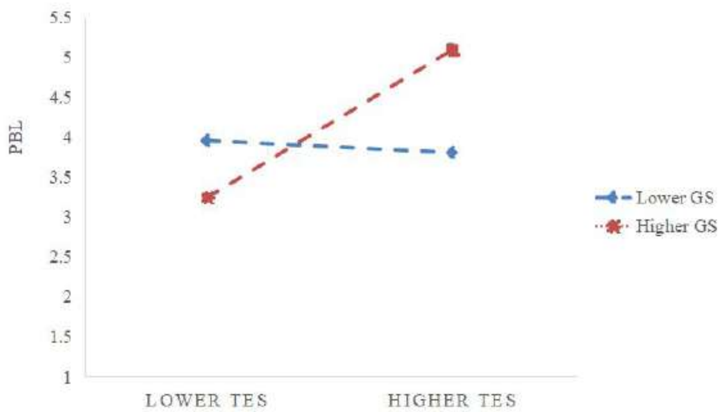
	R^2=.35****			
	F=45.37**			
	PBLV			
GS	.15****	.05	0.06	0.24
TESE GS	.50*****	.06	0.38	0.62
CTA GS	-.55*****	.07	-0.70	-0.40
	R^2=.71***			
	F=125.65			

*Note: SE stands for standard error, β stands for standardized coefficient, and 95% for upper and lower 95% confidence intervals. 95% confidence interval for the direct and conditional indirect effects based on 262 samples. Before analysis, all continuous variables were standardized. CTA stands for creative thinking attitudes, GS stands for gender stereotyping, TESE stands for technology and engineering self-efficacy, PBLV stands for project-based learning values. ***p < .001; **p < .01; *p < .05.*

(i) Simple Slopes Analysis Between Gender Stereotype-Regulated TESE to PBLV

Figure 7 illustrates the analysis of simple slopes. The relationship between TESE and PBLV becomes stronger as gender stereotypes increase. Specifically, TESE has a stronger effect (β = 0.74; p < 0.001) on PBLV when gender stereotypes are higher (M+1SD), and a weaker effect (β = 0.11; p = 0.1268) when gender stereotypes are lower (M-1SD).

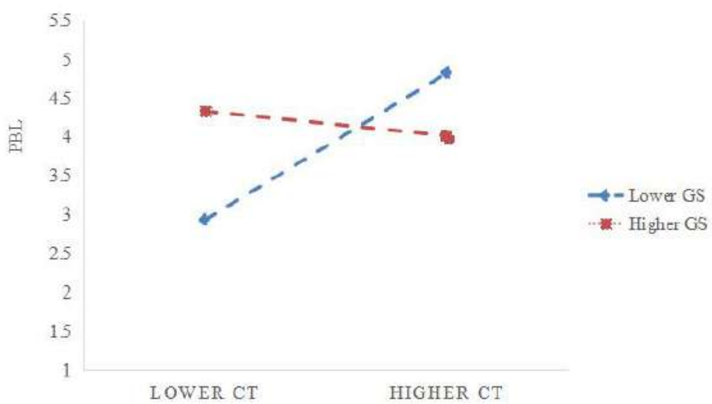
Figure 7.
The Relationship between gender stereotype-regulated TESE to PBLV



(ii) Simple Slopes Analysis Between Gender Stereotype-Regulated CTA to PBLV

Figure 8 presents the outcomes of the simple slopes analysis. The relationship between CTA and PBLV weakens as gender stereotypes increase. Specifically, CTA has a stronger effect (β = -0.63; p < 0.001) on PBLV when gender stereotypes are lower (M-1SD) and a weaker effect (β = 0.63; p = 0.59) when gender stereotypes are higher (M+1SD).

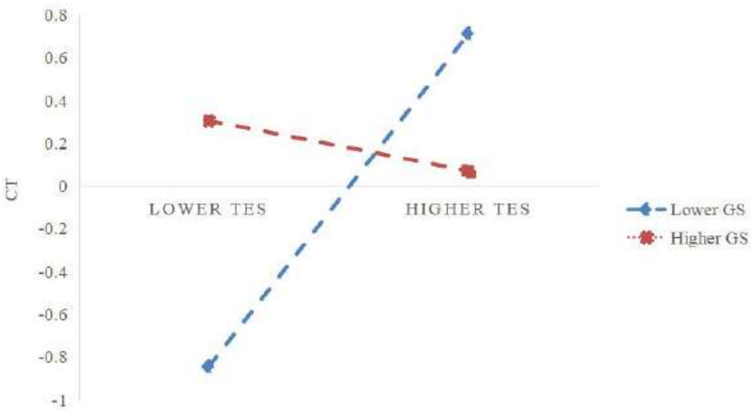
Figure 8.
Moderating role of gender stereotypes in the relationship between CTA and PBLV



(iii) Simple Slopes Analysis Between Gender Stereotype-Regulated TESE to CTA

Figure 9 shows the simple slopes analysis results. The relationship between TESE and CTA weakens as gender stereotypes increase. Specifically, TESE has a stronger effect (β = -0.63; p < 0.001) on CTA when gender stereotypes are lower (M-1SD) and a weaker effect (β = 0.63; p = 0.51) when gender stereotypes are higher (M+1SD).

Figure 9.
Moderating role of gender stereotypes between TESE and CTA



7.DISCUSSION

7.1. TESE is positively related to CTA

High self-efficacy is associated with a more positive attitude towards creativity. This connection between Teacher Efficacy Self-Efficacy (TESE) and Creative Thinking Attitudes (CTA) is supported by research indicating that individuals with higher self-efficacy are more confident and thus more likely to engage in creative thinking and problem-solving without fear of judgment. Conversely, those with lower self-efficacy may shy away from complex tasks. This correlation suggests that fostering self-efficacy could enhance creativity in technology and engineering education, where students with greater self-efficacy also tend to perform better academically and show more motivation.

7.2. CTA is positively related to PBLV

The study confirmed a positive link between Creative Thinking Attitudes (CTA) and perceptions of the value of project-based learning (PBLV). Research has consistently shown that project-based learning (PBL) can significantly boost students' creativity, suggesting it's an effective instructional approach to foster creative skills. PBL not only enhances knowledge but also aids in developing critical, creative, and problem-solving abilities among learners.

7.3. TESE is positively related to PBLV

The study found a positive correlation between Teacher Efficacy Self-Efficacy (TESE) and the value of project-based learning (PBLV), indicating that enhanced self-efficacy in technology and engineering can lead to a greater appreciation of project-based learning. Prior research supports that PBL not only bolsters students' self-efficacy but also their satisfaction with their education, offering gains over traditional teaching methods.

7.4. Gender Stereotypes Moderated the Relation Between CTA and PBLV

The study highlights gender stereotypes as a significant influence on the relationship between Creative Thinking Attitudes (CTA) and perceptions of project-based learning's value (PBLV) in technology and engineering education. It was found that students with less pronounced gender stereotypes have more positive CTA and a stronger belief in the benefits of PBL. Prior research indicates that creative thinking does not differ significantly between genders, suggesting that observed disparities in technology and engineering may stem from gender stereotypes lowering confidence, particularly in female students. This may lead to the false impression that male students are more adept in technological creativity. Efforts to promote equity in science and engineering education are needed to combat these stereotypes and ensure that all students, regardless of gender, have the opportunity to succeed.

8.CONCLUSIONS, IMPLICATIONS AND LIMITATIONS

8.1. conclusions

Utilizing bio-ecological system theory and the person-process-context model, our model probed the effects of gender stereotyping on attitudes towards creative thinking (CTA) and the valuation of project-based learning (PBLV) in technology and engineering education (TEE). The findings indicated a positive correlation between CTA and PBLV, and between technology and engineering self-efficacy (TESE), CTA, and PBLV. Notably, it emerged that gender stereotypes moderate the connections among these variables, with a marked influence on students' TESE, thereby affecting their CTA and TEE engagement. Additionally, the study highlighted the role of gender stereotypes in shaping students' self-perception of competency in TEE, impacting their long-term engagement in project-based learning and career paths. Enhancing TESE in light of gender stereotypes is crucial for balanced gender representation. The research offers actionable insights for educators and students to mitigate these stereotypical effects.

8.2. implications

Research indicates that an open learning environment fosters student creativity and that authenticity in project-based teaching enhances creative thinking and learning outcomes. Teacher involvement is crucial in cultivating students' creative thinking and self-efficacy, achieved through inquiry-based learning, prompt feedback, and diverse teaching methods. To combat gender stereotypes in technology and engineering education (TEE), teachers should ensure their materials and resources reflect diverse gender achievements, establishing an accessible and unbiased learning space.

Moreover, studies show that gendered career aspirations form early, often by ages 11 to 12, highlighting the necessity of early intervention. With girls generally preferring occupations with a focus on family and social interaction, their interest in TEE tends to be lower. Early educational intervention can thus play a significant role in diminishing gender stereotypes and encouraging balanced gender representation in TEE from a young age.

8.3. limitations

When interpreting our findings, it is crucial to consider certain constraints. Our sample size was small, a limitation exacerbated by data collection challenges in the classroom, such as issues with data quality and student dropout, resulting in a final count of 262 participating students. Future research in Chinese secondary schools should aim for a larger, more balanced male and female sample to enhance the findings' representativeness and generalizability.

Additionally, the process of developing project-based learning valuation (PBLV), creative thinking attitudes (CTA), and technology and engineering self-efficacy (TESE) is gradual and influenced by external factors over time. The one-month timeframe of our study may not have sufficed to observe the full evolution of these variables. Longitudinal studies could provide better insights into how gender stereotypes impact these aspects.

Lastly, our study relied on quantitative scales to measure the impact of gender stereotypes on CTA, TESE, and PBLV. To achieve a more nuanced understanding, future research should incorporate qualitative methods like focus groups and interviews. A mixed-method approach could more thoroughly investigate the complex influences of gender stereotypes.

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Developed of the Engineering and Technology Lesson Plans Analysis Instrument based on student deeper learning

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Abstract

In engineering and technology education, lesson plans are crucial, as effective lesson designs ultimately enhance classroom outcomes. However, existing engineering and technology lesson plan analysis instruments do not consider the depth of student learning or focus on a particular lesson. To address the need to assess the depth of student learning and to evaluate whole lesson plans in engineering and technology education, we developed the Engineering and Technology Lesson Plans Analysis Instrument based on student deeper learning (ETLPAI-DP). We employed multiple rounds of expert consultation and case analysis to develop and validate the ETLPAI-DP iteratively. First, we designed eight primary indicators and 49 secondary indicators based on key aspects of deep learning drawing from the practice model in the "Deeper Learning" teaching reform project. Using the Delphi method, we conducted two rounds of expert consultations, resulting in six primary indicators (competency-oriented learning objectives, value-driven learning themes, challenging learning tasks, organically embedded assessments, diverse and open learning environments, and deep reflective teaching improvement) and 20 secondary indicators. Next, we conducted a third round of expert consultations and used the Analytic Hierarchy Process to assign weights to the indicators in the evaluation protocol. Finally, we applied ETLPAI-DP to analyze six lesson plans written by technology teachers. The analysis showed that the two highest-scoring lesson plans were also the best-performing in previous classroom teaching competitions, demonstrating that ETLPAI-DP can effectively differentiate the quality of lesson plans.

Key Words: Engineering and technology education, lesson plan, Deeper Learning, Expert

1. INTRODUCTION

In engineering and technology education, lesson plans are crucial because effective course design ultimately enhances classroom outcomes (Alrwaished 2024; Çalış 2020). Lesson plans are unique artifacts of teacher perspectives and practices, providing more insight into teachers' preferences for teaching and curriculum than any other artifact (Sias et al. 2017). Lesson planning is not done in a single step; novice teachers receive feedback from their supervisors during the planning process (Sias et al. 2017). Therefore, an assessment tool for lesson plans is necessary to evaluate their quality and provide further feedback for improvement.

Representative and influential Lesson Plan evaluation tools include the Science Lesson Plan Analysis Instrument (SLPAI)(Jacobs, Martin, and Otieno 2008), and the 5E Inquiry Lesson Plan (SLPAI)(Goldston et al. 2013)）. Each tool has its pros and cons: SLPAI has a high usage threshold for evaluators; and the 5E Inquiry Lesson Plan evaluation tool is difficult to apply to lessons not designed using its framework. Moreover, these tools do not consider the depth of student learning and are not specifically designed for engineering and technology education. To address the need for evaluating student learning depth and lesson plans in engineering and technology education, we developed a tool for analyzing lesson plans based on student deep learning.

2. THEORETICAL BACKGROUND

Marton and Säljö (1976) first proposed and explained the concepts of deep learning and surface learning, suggesting that employing deep learning methods enables students to better and more effectively remember relevant information. Guo (2020) identified the components of deep learning as: competence-oriented goals, guiding themes, challenging tasks, active intrinsic motivation, advanced social emotions, and correct values. This definition clarifies the mechanisms by which deep learning occurs, recognizing the significance of teaching objectives and content, and elucidating the purposes of education and teaching.

3. ASPECT DESIGN

The teaching improvement of deep learning emphasizes design practice, which includes four main aspects: deep learning objectives, learning topics, deep learning activities, and continuous evaluation. General technology subject lesson plan evaluation of level 1 index: literacy oriented learning objectives, value leading learning theme, reliable learning situation, challenging learning task, deep processing learning process, organic embedded learning evaluation, multiple open learning environment, the depth of reflection teaching improvement.

By analyzing the core connotation of the eight elements in the lesson plan framework of Engineering and Technology Lesson Plans Analysis Instrument based on Student Deeper learning (ETLPAI-DP), a total of 49 representative sub-aspect are decomposed, shown in Table 1.

Table 1.
Framework of Engineering and Technology Lesson Plans Analysis Instrument based on student deeper learning

Aspect	*sub-aspect*
Literacy-oriented learning objectives	Guidance, integrity, advancement, process, ontology, appropriateness, measurement, standardization, objectivity
Value-led learning topics	Leading, systematic, structural, advanced, interesting, value
Real and reliable learning situations	Practical, inquiry, authenticity, migration, social, complexity
A challenging learning task	Challenging, authenticity, advanced, systematic, appropriate, rationality, value
The learning process of deep processing	Initiative, construction, generation, logic, experience, migration
Learning evaluation of organic embedding	Sustainability, feedback, consistency, scientific, process, value-added, diversity
Diversified and open learning environment	Physical environment, virtual environment, human environment
Teaching improvement of deep reflection	Process, scientific, systematic, timeliness, consistency

In order to ensure that the secondary index and its corresponding operational description are more concise and representative. On this basis, the expert consultation table was prepared, and two rounds of expert consultation were conducted using the Delphi method. Based on the expert consultation and opinions in the first round, two first-level indicators were merged, 20 second-level indicators were deleted and merged, and the operational description under the second-level indicators was revised and supplemented. After that, the results of the first round of modification will be reported to the experts, and the second round of expert consultation will be conducted. According to the statistics of the second round of expert consultation, the average scores of the first and second-level indicators were above 4.5, the frequency of full marks was above 0.5, the standard deviation was less than 1, and the coefficient of variation was less than 0.25, indicating that the concentration of experts' opinions in the second round of expert consultation was high.

4. SCORING WEIGHT DESIGN

According to the analysis steps of the hierarchical analysis method, the hierarchical structure model of ETLPAI-DP is established first, and then the pairwise judgment matrix is constructed according to the relative relationship, calculating the weight of each element, and finally conducting the consistency test, and then the final weight value of the evaluation model is determined.

4.1. Establish an evaluation hierarchy model

After formulating the evaluation indexes of the criterion layer and the sub-criterion layer through two rounds of Delphi consultation method, the evaluation structure model was drawn out according to the affiliation between the indicators and the lesson plan scheme of six units

4.2. Construct a pairwise judgment matrix

The judgment matrix can be constructed by the scale of 1 to 9. In this study, 13 general technical education experts were consulted in the third round of expert consultation. Taking the scoring results of one of the experts as an example, the judgment matrix can be obtained, see Table 2 for details.

Table 2.
The matrix of ETLPAI-DP index judged by an expert

metric	A1	A2	A3	A4	A5	A6
A1	1	3	1	2	3	1
A2	1/3	1	1/5	1/5	1/3	1/5
A3	1	5	1	5	5	5
A4	1/2	5	1/5	1	3	2
A5	1/3	3	1/5	1/3	1	1
A6	1	5	1/5	1/2	1	1

4.3. Calculate the index weight vector

According to the constructed judgment matrix, the weight of the each evaluation element is calculated. The calculation steps are performed as follows:

First, normalize the judgment matrix A by columns:

$$a_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} ,(i,j = 1, 2, \cdots 6)$$

Then the sought matrix is added according to each line of elements to obtain the feature vector:

$$\overline{w_i} = \sum_{j=1}^{n} a_{ij}$$

Finally, the weight of the index is obtained by the normalization of the feature vector.

$$w_i = \frac{\overline{w_i}}{\sum_{j=1}^{n} \overline{w_j}}$$

Therefore, the expert believes that the weights of the six first-level indicators of deep learning lesson plan are 0.2128,0.0414,0.3926,0.1557,0.0797 and 0.1178 respectively.

The weight value of each index is only statistically significant when it meets the consistency test of each judgment matrix. The calculation steps are as follows:

(i) Calculate the maximum eigenvalue of the judgment matrix:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nw_i}$$

Where, n is the order of the judgment matrix.

(ii) The consistency index of the calculation and judgment matrix:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

The larger the value of, the greater the deviation of the judgment matrix from the full consistency, and vice versa.

(iii) Calculate the consistency ratio:

$$CR = \frac{CI}{RI}$$

Where, is the random consistency index, you can look up the order table

$$CR < 0.10 \lambda_{max} = 6.5677 CI = \frac{\lambda_{max} - n}{n-1} = 0.1135 \ RI = 1.24 CR = \frac{CI}{RI} = \frac{0.1135}{1.24} = 0.0915 < 0.10$$

reach. At that time, it shows that the judgment matrix consistency meets the requirements, and vice versa. With the score of this expert, we get,, when n=6,,. Therefore, it can be considered that the first-level index weight of the expert in the lesson plan evaluation of the deep learning unit meets the consistency requirements.es New Roman size, 9-point font, fully justified, with single line spacing.

4.4. Calculate the index weight vector

Following the above steps, a judgment matrix was constructed from the questionnaire data of the remaining 12 experts, and the data were imported into the Yaahp statistical software to calculate the average weight values.

According to the calculation, the final weights of the first-level indicators of the lesson plan evaluation of the 6 units are 0.2108,0.1934,0.1812,0.1700,0.1557 and 0.0888 respectively. At the same time, the calculation of the second-level index weight under each element can obtain the hierarchical weight of the evaluation index and the comprehensive weight value of each index, as shown in Table 3.

Table 3.
The scoring weight of ETLPAI-DP index judged by an expert

Sub-aspect	weight	sort	Secondary indicators	weight	Comprehensive weight
A1 literacy-oriented learning objectives	0.2108	1	B1 reflects the orientation of the problem-solving ability	0.2696	0.0568
			B2 Progress of withdrawal learning objectives	0.1517	0.0320
			B3 Objectivity of the withdrawal training objectives	0.1823	0.0384
			B4 suitability of withdrawal cultivation target	0.1933	0.0407
			B5 Normalization of learning goal formulation	0.2030	0.0428
A2 value-led learning topics	0.1557	5	B6 reflects the guidance of value judgment	0.2442	0.0380
			B7 reflects the authenticity of the question	0.2411	0.0375
			B8 reflects the suitability of the problem-solving ability	0.2386	0.0372
			B9 reflects the interest of the question	0.2761	0.0430
A3 Challenging learning tasks	0.1812	3	B10 withdrawal learning task challenge	0.1197	0.0217
			B11 The advancement of the withdrawal ability cultivation	0.1129	0.0205
			B12 cash withdrawal system to solve the problem systematically	0.1412	0.0256
			B13 the appropriateness of the withdrawal situation	0.1445	0.0262
			B14 withdrawal solution to the problem expansion	0.1304	0.0236
			B15 The subjectivity of the withdrawal learners	0.2070	0.0375
			B16 the generation of the withdrawal learning process	0.1444	0.0262

			B17 Persistence of the withdrawal process evaluation	0.1199	0.0232
			B18 The feedback of the withdrawal process evaluation	0.1453	0.0281
A4 organic embedding	0.1934	2	B19 The consistency of multi-subject evaluation for cash withdrawal	0.1373	0.0266
			The nature of B20 cash withdrawal evaluation index is scientific	0.3030	0.0586
			B21 The diversity of the withdrawal evaluation dimensions	0.1291	0.0250
			B22 the appreciation of the withdrawal feedback	0.1654	0.0320
			B23 The physical environment presented by the withdrawal problem	0.4263	0.0379
A5 A diverse and open learning environment	0.0888	6	B24 Virtual environment for the withdrawal problem solving process	0.1789	0.0159
			B25 The humanistic environment of the learning atmosphere	0.3947	0.0350
			B26 cash withdrawal improvement plan is scientific	0.3512	0.0597
			B27 A systematic withdrawal improvement process	0.2327	0.0396
A6 Instruction improvement of deep reflection	0.1700	4	B28 The timeliness of cash withdrawal teaching improvement	0.2241	0.0381
			B29 The consistency of cash withdrawal teaching improvement and learning objectives	0.1919	0.0326

With deep learning as the entry point, according to the weight value of each level index, the importance distribution of each index to the evaluation target is A1＞A4＞A3＞A6＞A2＞A5, Explain that the literacy-oriented learning objectives play a very important role in the lesson plan.

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A Study on the Construction of a Three-Dimensional Model for the Cultivation of Technological and Engineering Thinking in Primary and Middle Schools

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Abstract

Technology and engineering thinking is an important part of technology and engineering literacy, which is the key factor to support the success of engineering activities. Through the examination of engineering, philosophy and education, it is found that engineering thinking can be divided into three dimensions: one is time or process dimension, the second is logic or reasoning dimension, and the third is knowledge or method dimension. Students of different ages have great differences in the development of technology and engineering thinking, reflecting significant stage characteristics. The three-dimensional model of technology and engineering thinking cultivation for primary and middle school students can be constructed through the implementation of a complete project, the evocation of an iteractive process and the guidance of knowledge construction . Based on the 3D model, the intelligent generation platform of engineering design process is developed. The platform outstands three functions: guiding the engineering design process, generating resources based on knowledge graph, and tracking generating process , which injects strong power into the cultivation of technology and engineering thinking.

Key words: primary and middle school students ,technology and engineering thinking , 3D model, generative artificial intelligence

In engineering practice, people, as the main body of the project not only pay a certain amount of physical labor but also carry out a variety of thinking activities, among which the dominant thinking activities are mainly engineering thinking. Only the kind of engineering activities supported by the sound engineering thinking, because it can fully consider the various factors involved in the engineering activities, can be balanced in the engineering, to achieve success. In recent years, many countries have paid attention to the cultivation of engineering literacy among students in the basic education stage, and engineering thinking is an important part of it. Asto the Standard for Technology and Engineering Literacy, the International Association for Technology and Engineering Education (ITEEA) has put forward the technical and engineering practice ability and the grade level requirements to be developed in the K-12 stage, including: systematic thinking, creativity, hands-on production, critical thinking, optimism, cooperation, communication and ethics attention. China ’ s General Technology Curriculum Standards for Ordinary Senior High Schools (2017 edition,2020 Revision) has regarded engineering thinking as one of the core qualities of general technical subjects for ordinary senior high schools, and defined it as " planning thinking with systematic analysis and comparison as the core" . However, the existing research on engineering thinking is still under study.In particular,there is a lack of research on the occurrence mechanism of engineering thinking.This predicanment results in the lack of solid theoretical foundation for the cultivation of engineeting thinging. Therefore,it is essential to conduct an in-depth research.

1. THREE DIMENSIONS OF TECHNOLOGY AND ENGINEERING THINKING

1.1. Engineering perspective

In 1969, Hall,the American engineer, proposed the system engineering methodology of "3 D structure", also known as the Hall 3 D Structure. Hall 3 D Structure divides the whole process of system engineering into closely connected stages and steps. At the same time, it also considers various professional knowledge and skills and thinking procedures needed to complete these stages and steps, forming a three-dimensional space structure composed of time dimension, logic dimension and knowledge dimension. Hall 3 D Structure, time dimension is the whole process of system engineering activities starting from beginning to end, including planning stage, development stage, formulation stage, production stage, installation stage, operation stage and update stage. Logic dimension refers to the work content and thinking procedure that should be carried out in each stage of time dimension.It includes seven logical steps: problem definition, goal determination, system synthesis, system analysis, system optimization, decision-making and implementation. Each stage has certain work content, which has both universality and particularity based on specific engineering projects. Both of which determine that we need to use certain thinking procedures to work in each stage. To solve complex system problems requires comprehensive application of relevant knowledge. The "knowledge dimension" proposed in Hall 3 D Structure actualh is the knowledge synthesis needed to solve complex system problems, including professional knowledge and skills of society, art, commerce, engineering, architecture, law, medicine and computer.Every stage of the time dimension of system engineering activities involves the application of integrated knowledge.

1.2. Philosophical perspective

Xu Changfu believes that there are two different ways of thinking in the human brain: one is the theoretical thinking for constructing theory, which operates in accordance with the law of logically introducing conclusions from the premise; the other is the engineering thinking for designing engineering, which needs to integrate several theoretical systems at different levels illogically. Xu Changfu also points out that it is logic that brings so many different entities together to construct engineering logic. Logic is the inevitable connection between attributes, and these attributes are the various properties and characteristics of individual existential things . Engineering thinking is the unity of logic and non-logic, and it is the integration of the logic within the plate and the coordination between the plates. With practical rationality,Wang Zhenzhou proposes a three-level model of enginnering thinking:the first is the logic model. Engineering thinking is neither the deductive reasoning of "theoretical thinking" nor inductive reasoning.It is practical reasoning. It starts from the desire and the will of the actor, to find action plans to achieve the will. The second is the integrated model.Engineering thinking must integrate scientific thinking, technical thinking, humanities and social science thinking methods as well as the traditional, empirical, and local methods.The third is the context-process model.Engineering thinking must always run through every link and every stage,and through the whole process of engineering action. Engineering thinking necessarily has a context-time structure that unfolds with engineering actions within a specific spatial field. In this three-level model, there are three dimensions of reasoning, knowledge and process, respectively. It can be seen that engineering thinking is a kind of practical rationality, which extends from the three dimensions of reasoning, method and process, driven by the value intention of the actors.

1.3. Pedagogy perspective

The New Generation Scientific Standards (NGSS) divides the engineering design process into three core stages. First, define and divide the engineering problems, i.e.state the probiem to be solverd as clearly as possible in terms of success criteria and constraints or limitations; Second, design the solution to the engineering problems, like, propose different possible solutions, then evaluate these solutions to find out the best one meeting the standards and constraints; and third, to optimize the design solutions, i.e.systematically test and improve the design by weighing the important and sub-important functions. The Cincinnati Engineering Intensive Mathematics and Science (CEEMS) project also developed the engineering design process (engineering design process, EDP) model. China's general technology course divides the technology and design process into design analysis, scheme conception, physical and chemical production, testing and evaluation etc.It can be seen that the engineering design process in technology and engineering education is equivalent to the logical dimension of the planning and development stage in the Hall 3 D Structure, and also equivalent to the practical reasoning dimension in the philosophical sense. The CEEMS project also developed two types of guidance problems as the starting point of EDP: one is EDP guidance problems and the other is knowledge guidance problems. From this point of view, engineering design process model mainly focuses on the development of logical dimension and knowledge dimension of engineering thinking. And engineering design process is believed to promote students' development in knowledge application and construction, reasoning, metacognition, executive function, self-regulation, learning motivation, etc.

In conclusion, although the specific contents of certain dimensions may differ in engineering, philosophy, and pedagogy regarding the mechanisms of engineering thinking, the division of dimensions is basically consistent. That is, starting from the subjective will or engineering goals, the operation of engineering thinking is reflected in three dimensions: the first is the time or process dimension;the second is the logic or reasoning dimension, and the third is the knowledge or method dimension.

2. DEVELOPMENT CHARACTERISTICS OF TECHNOLOGY AND ENGINEERING THINKING AMONG PRIMARY AND MIDDLE SCHOOL STUDENTS

Students of different ages have great differences in the development of technology and engineering thinking, reflecting significant stage characteristics.

2.1. Time or Process Dimension

Primary school students can have a certain planning ability for the progress, manpower, and material resources of a project, but they are still relatively weak in terms of overall and rational planning. Junior high school students can have an overall plan for each link of the project process, but they have not yet been able to fully anticipate potential problems at each stage and make contingency plans, and their regulatory capacity is still relatively weak. Senior high school students can basically plan for each stage and process of engineering activities, coordinate the arrangement of time, manpower and material resources at different stages to improve efficiency.They can reasonably anticipate potential problems at each stage and make contingency plans, and implement monitoring during the operation of the project.

2.2. Logical or Reasoning Dimensions

Primary school students are curious about things and like to discover problems by touching objects and engaging in hands-on experiences. Their understanding of system engineering problems is weak, and they are not yet able to clearly define the multiple factors that affect problem-solving. They have a weak ability to solve complex system engineering problems. Junior high school students can define the relevant factors that affect problem-solving and have a preliminary understanding of system engineering concepts, that is: What goals should the project achieve? What problems need to be solved logically to achieve this goal? How to make choices when there is a logical conflict? What steps need to be taken to solve these problems?And how to arrange these steps? And so on.Junior high school students can not only analyze multiple factors that affect the achievement of project goals but also pay attention to the impact of changes in these factors, thus being able to use these analytical results to solve problems in engineering design and implementation. They can establish an experiential model of the relationship between factors and results through certain practices, but this analysis is still at an empirical and vague stage, mostly non-quantitative, lacking precise analysis. Senior high school students can consciously explore multiple factors affecting the achievement of project goals and their precise relationship with the results.Their quantitative model thinking begins to form, thus enabling more logical system comparison, planning, selection, and optimization.

2.3. Knowledge or Method Dimension

Primary school students' knowledge reserves are not yet rich enough, and when solving problems, their thinking is largely emotional, that is, they mainly rely on intuitive impressions formed by observing technical cases and hands-on experiences to solve problems. Junior high school students gradually expands their knowledge scope, and they can begin to use their learned knowledge to analyze problems when participating in technical and engineering projects. Senior high school students' knowledge base further broadens, and their logical thinking also tends to mature. When engaging in technical and engineering projects, they can apply mathematical models to analyze and solve problems.

3. CONSTRUCT A THREE-DIMENSIONAL MODEL FOR THE CULTIVATION OF TECHNOLOGY AND ENGINEERING THINKING IN PRIMARY AND MIDDLE SCHOOL STUDENTS

3.1. Implement complete projects to develop the time dimension of engineering thinking

Through progressive projects as carriers, integrated cultivation can be carried out, such as taking the design and production of small cars as the theme, starting from designing rubber band-powered cars, gradually advancing to gravity-powered cars, belt-driven gear cars, and other thematic projects. Moreover, it is important to value the development of the time dimension of engineering thinking through the implementation of complete engineering practice projects. In the early grades, students can first observe physical objects or watch technical cases. Then they are encouraged to identify factors to consider for achieving engineering goals through questioning, but the factors should not be too many. Encourage students to boldly experiment and make mistakes, thereby discovering problems and getting improved. As the grades increase, the number of factors to consider in engineering cases and projects can be gradually increased. Encourage students to engage in advanced trial and error, that is, to improve while doing. And by senior high, the complexity of engineering cases and projects can be further increased. Students are encouraged to use interdisciplinary knowledge and establish mathematical models to solve problems.

3.2. Induce the iterative process to develop the logical dimension of engineering thinking

Engineering thinking does not pursue the best solution, but the optimal one. It only occurs in complex engineering practice, thus requiring the presentation of complex engineering situations through setting success criteria and constraints or limitations. This induces the operation of the logical dimension of engineering thinking. At the same time, to guide the development of the logic dimension, it is also necessary to build scaffolding for logical thinking for students, such as developing guiding questions, forming a problem-solving process guided by a chain of questions.For example: during the "clarify and define the problem" phase, one should consider what the problem is; what the constraints are and what the requirements are; during the "collect information" phase, one should consider what he needs to know;whether there is an existing design; and what the advantages and disadvantages of the existing design are; during the "identify alternative solutions" phase, one should consider which solutions can meet the design requirements; whether these solutions have accurate scientific data as evidence, and whether these solutions are creative, and so on.

3.3. Guide the knowledge construction to develop the knowledge dimension of engineering thinking

First, it is necessary to apply theoretical knowledge to work on the logic dimension. EDP also proposes to design knowledge-guided questions related to problem-solving. These guiding questions should directly target the academic knowledge that must be learned and focus on covering the learning objectives of knowledge across various curriculum standards.For example, to design a structure with certain performance requirements may require logical thinking from the aspects of height, load-bearing capacity, stability, aesthetics, etc. Therefore, it involves knowledge of the mechanical properties of selected materials, processing techniques, connection methods, production efficiency, personnel arrangement, production costs, etc. Thus, on one hand, there is a need for certain engineering knowledge; and on the other hand, there is a need for the integration of interdisciplinary knowledge. Secondly, as a practical rationality, the operation of engineering thinking relies not only on theoretical knowledge but also on the application of practical or situational knowledge. Therefore, the cultivation of engineering thinking needs to focus on the development in the knowledge dimension. As far as the subject of knowledge is concerned, on one hand, it is necessary to emphasize the integration of personal knowledge;and on the other hand, it is necessary to focus on the integration of group knowledge, enabling students to develop a collaborative and communicative way of thinking. As far as the nature of knowledge is concerned, on one hand, it is necessary to integrate existing knowledge; and on the other hand,it is necessary to construct new knowledge.

4. GENERATIVE ARTIFICIAL INTELLIGENCE EMPOWERS TECHNOLOGY AND ENGINEERING THINKING CULTIVATION

Based on a three-dimensional model for the cultivation of technology and engineering thinking, the project team has developed an intelligent generation platform for engineering design processes. The platform deeply learns and cleverly applies the core concepts of Knowledge Graph, significantly enhancing the performance of search engines through precise organization and reconstruction of resource information. The platform uses nodes (entities) and edges (relationships between entities) as basic units to construct a complex yet orderly multi-relational graph. The three major technological approaches of the platform have injected strong momentum into the cultivation of technology and engineering thinking.

4.1. Guide the engineering design process to empower the development of the logic dimension

This route involves knowledge extraction and integration, construction of an engineering design process framework, knowledge graph filling and optimization, automated construction, and the application of multimodal large language models, among others. Students can use the intelligent platform to generate engineering project design logical graphs around self-selected topics. This path, with its unique generative mechanism, encourages students to actively explore and innovate independently ,which effectively stimulates their creativity. At the same time, generative artificial intelligence simulates real-world problem scenarios, providing students with valuable practical opportunities to train their abilities in problem identification, analysis, and resolution, which can significantly enhance their technical and engineering thinking levels.

4.2. Generate resources based on knowledge graph to empower the development of knowledge dimension

This route covers the key steps of knowledge graph construction, cue word engineering, resource generation and selection, automatic optimizer and so on. In the face of complex and ever-changing technological and engineering challenges, generative artificial intelligence can assist students in integrating and applying interdisciplinary knowledge, connecting new knowledge in related fields, and providing students with a more comprehensive and integrated perspective and solutions.

4.3. Trace generative process to empower development in the time dimension

This route involves knowledge extraction and integration, project-based framework construction, knowledge graph filling and optimization, automated construction, and the application of multimodal large language models.Through intelligent analysis of students' project learning progress and feedback, generative artificial intelligence can dynamically adjust learning content and difficulty to achieve personalized instruction. This intelligent learning method not only stimulates students' interest and motivation in engineering design, but also significantly improves their efficiency and quality.

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Promoting Primary School Students' Creativity via Reverse Engineering Pedagogy in Robotics Education

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Abstract

Creativity is an essential basic skill for students. In this study, the reverse engineering pedagogy (REP) was applied to primary school students' robotics education course, with the aim of investigating the influence of REP and project-based pedagogy (PBP) on the cultivation of students' creativity. A quasi-experimental study that utilized a non-equivalent groups design was conducted with 91 fifth-grade students, comprising a control group (n = 46) who received the PBP intervention, and an intervention group (n = 45) who received the REP intervention. Creative self-efficacy, Torrance Tests of Creative Thinking Figural (TTCT-Figural), and assessment of the students' robotic creative products were conducted to evaluate students' creativity. In addition, t tests, ANCOVA, and ANOVA were used to analyze the data to determine whether REP could improve students' creativity better than PBP. The results showed that REP could enhance students' creative self-efficacy and their robotic creative products score more than PBP could, but not the TTCT-Figural score after the confounding effect of fluency was controlled for. In the intervention group, creative self-efficacy and creative thinking were improved after intervention. Overall, REP has more advantages than PBP for promoting primary school students' creativity. The findings of this study provide a reference and teaching strategies guidance for the cultivation of K-12 students' creativity in robotics education.

*Key words**:** creativity; reverse engineering pedagogy; creative thinking; robotics education; creative self-efficacy*

1. INTRODUCTION

In the 21st century, creativity is a core factor of global competition and a capability that individuals require to address emerging challenges (Vincent-Lancrin et al., 2019). Creative thinking as a thinking process related to individual participation in creative work which can improve an individual's abilities, such as their metacognitive ability, academic success, future career success, and social participation (Israel-Fishelson & Hershkovitz, 2022; Organization for Economic Cooperation and Development (OECD), 2019). Therefore, education systems in many countries (e.g., South Korea, China, Singapore, etc.) have incorporated creativity into their goals through education policies, and creativity has become an essential learning objective for all K-12 students (Bolden et al., 2020; Ozkan & Topsakal, 2021; Yang et al., 2020). However, according to the Program for International Student Assessment (PISA) 2021 creative thinking framework, no more than 7% of students were able to autonomously and creatively apply scientific knowledge to a variety of novel and unfamiliar situations (OECD, 2019). Therefore, fostering K-12 students' creativity is still an important issue that warrants continuous attention.

Educational robotics activities that combine multidisciplinary skills provide a platform for cultivating students' academic achievement and creativity with an extremely flexible and challenging learning environment (Guven et al., 2022; Yang et al., 2020; Zhang & Zhu, 2022). Creativity in robotics education supports students to explore educational robots with different functional types by building and programming, which are tangible technological objects capable of interaction (Leroy et al., 2021). The integration of digital technology products into teaching activities has a certain role to play in promoting students' creativity (Chen et al., 2020; Tang et al., 2022), but students may just play instead of thinking if they do not receive adequate guidance from teachers (Bers et al., 2019). Furthermore, creativity is not actively supported, or in some cases it is even discouraged in the education system (Patston et al., 2021). Teachers and students are accustomed to a stable way of teaching and learning under the influence of the emphasis on standardized tests, and rarely try creative ways to carry out learning activities (Rahimi & Shute, 2021). Some educators believe that cultivating students' creativity in school means having to neglect some subjects in the curriculum (OECD, 2019). As a result, teachers rarely take action to foster students' creativity in courses, instead focusing on achieving academic educational goals (Karwowski et al., 2020). Therefore, one of the feasible ways to enhance students' creativity is to adjust the teaching strategy in robotics education (Chen et al., 2020; Xia & Zhong, 2018; Zhong et al., 2021).

SCAMPER, which refers to substitution, combination, adaptation, modification, put, elimination, and rearranging or reversing (Rahimi & Shute, 2021), is a method that can enhance individuals' curiosity, provide some strategies to exploit their imagination, and stimulate them to generate diverse ideas (Gu et al., 2022). For example, Wu and Wu (2020) found that university students' creativity could be improved by applying SCAMPER and project-based learning in engineering education. Any of the components of SCAMPER can help students generate new ideas (Rahimi & Shute, 2021). Reverse Engineering Pedagogy (REP), which has some similar ideas to the modification strategy of SCAMPER, aims to use tools to improve previous ideas. Reverse engineering is the process of reverse development and manufacturing of a known product; thus, REP emphasizes the understanding and expression of products from external forms to function, which provides effective ideas for solving open problems (Plaza et al., 2018; Vukašinović & Duhovnik, 2019). Students taught with REP need to dissect and redesign products, a process that stimulates creativity and provides students with a bridge which allows them to understand the relationship between the basics of product design and the principles acquired in textbooks (Bertoni, 2019; Lur et al., 2022). Practicing open-ended real tasks and learning from mistakes and failures greatly helps creativity development in educational robotics tasks (Yang et al., 2020). Therefore, REP has the potential to positively impact K-12 students' creativity. A positive impact of REP on primary school students' creative self-efficacy compared with the project-based teaching method was observed by Zhong et al. (2021). However, as REP requires the instructor to show a finished robot project to learners, it may limit the imagination and creativity of the learner. For example, some studies (e.g., McLellan & Nicholl, 2011; Schut et al., 2020) have indicated that showing students a complete product and analyzing its functions and features may fix students' thoughts on the given product and thus inhibit their creativity. Prior studies have explored the effectiveness of REP in terms of enhancing students' learning performance, design thinking, and computational thinking (e.g., Abdüsselam et al., 2022; Akerdad, et al., 2022; Ladachart et al., 2022; Liu et al., 2023), but few researchers have explored the effectiveness of REP in terms of creativity in K-12 robotics education. To address this gap, this study aimed to investigate whether REP could enhance students' creativity in robotics education.

In addition, project-based pedagogy (PBP) is the most widely used approach in robotics education (Darmawansah et al., 2023; Sun et al., 2022). Students who receive PBP are encouraged to seek solutions in active learning activities around real problems through the process of selection, planning, investigation, and production (Castro et al., 2018). Students who receive PBP in robotics education need to construct an entire project product from zero around complex and authentic questions according to their prior knowledge, which could include misconceptions (Garnjost & Lawter, 2019; Ladachart et al., 2022; Zhong et al., 2021). In contrast, REP initiates the redesign process whereby students are first exposed to a complete product that they need to observe (e.g., functionality, form, and physical principles) to gain a deeper understanding of the material, and then they reconstruct or optimize it (Bertoni, 2019; Lur et al., 2022; Wood et al., 2001). Thus, the present study attempted to determine whether putting REP into practice can improve primary school students' creativity better than PBP in the context of robotics education.

2. LITERATURE REVIEW

2.1. Creativity

Creativity can be understood from different perspectives; it involves personality characteristics, cognitive processes, environment variables, and novel and useful products defined within a social context (Dean et al., 2006; Plucker et al., 2004; Runco & Jaeger, 2012; Wechsler et al., 2018). For example, a creative individual is a person who often solves problems, designs products, or defines new problems in an area, in a way that is initially considered novel but is eventually accepted in a particular cultural context (Gardner, 1999). Creativity has been characterized as comprising four elements (Guilford, 1950), namely 1) Fluency: an individual's ability to produce a number of ideas via interpretable responses; 2) Flexibility: an individual's ability to analyze a situation from different points of view; 3) Originality: an individual's ability to produce unique or unusual ideas; and 4) Elaboration: an individual's ability to expand ideas that go beyond the minimum required. A creative person pays attention to details, and embellishes or accomplishes something creative to make it more aesthetically pleasing, understandable, and real. According to Guilford's creativity theory, Torrance (1969, 1974) developed a framework for creativity including fluency, flexibility, originality, and elaboration. The "4 Ps of creativity," proposed by Rhodes (1961), is currently one of the most widely accepted categories (Israel-Fishelson & Hershkovitz, 2022). It consists of four components: 1) Person, which refers to the creator's behavior, personality, quality, and self-perception; 2) Process, which refers to the cognitive processes, such as motivation and divergent thinking, involved in the creation of ideas by creators; 3) Product, which refers to the work that embodies the idea, such as the creation of handicrafts, etc.; and 4) Press, which refers to the influence of the environment on the creator. There are many definitions of creativity, but different definitions also typically focus on one of the four components. Eminent creativity is recognized by a professional field or society at large, whereas everyday creativity refers to originality and meaningfulness in the context of a wide range of everyday activities at work and leisure (Richards, 2001). To distinguish the level of creativity magnitude, a "four C" creativity framework was proposed by Kaufman and Beghetto (2009), which includes big-C, pro-C, little-C, and mini-C: 1) "big-C" is a level of genius that very few people can achieve in a lifetime; 2) "pro-C" is used to describe the professional creativity of an expert in a certain field; 3) "little-C" is an expression about creativity in everyday life that most people can understand; and 4) "mini-C" is used to express creativity in the learning process, which is influenced by the creator's development of knowledge and experience in the cultural and social context. In an educational context, a creative product is not an original or brand-new product for the world and general humans, but has personal meaning and is new for the learner.

Definitions of creativity in education are endowed with rich connotations. They vary from supporting economic growth and innovation via national policies and educational priorities to highlighting the importance of daily creativity (Stephenson, 2023). Learning experiences in a dynamic environment and atmosphere that enable learners to participate in an atmosphere of anticipation and expectation are essential conditions for creativity (Davies et al., 2013). In school, students' creativity is reflected in their creative expression, creative problem solving, and knowledge creation skills, which can be independently developed or used as learning topics in science, technology, mathematics, engineering, and other courses (Lucas & Venckuté, 2020). As a 21st-century essential skill, creativity can promote the improvement of other abilities of individuals (Israel-Fishelson & Hershkovitz, 2022; OECD, 2019); its importance is therefore becoming increasingly recognized (Bolden et al., 2020; Ozkan & Topsakal, 2021; Yang et al., 2020). However, student creativity levels are still far from what educators expect (OECD, 2019). Therefore, cultivating and promoting creativity is an important agenda of K-12 education.

2.2. Reverse engineering pedagogy

The concept of reverse engineering was first developed in the field of industrial practice and has been incorporated into educational activities (Dalrymple et al., 2011). Reverse engineering involves the analysis of existing processes or products to determine their components and their relationships (Bertoni, 2019), and can be used for developing products based on existing parts or products via disassembly activity (Lur et al., 2022). Reverse engineering pedagogy (REP) emphasizes that students explore existing products, reconstruct and optimize them, and make micro-innovations (Lur et al., 2022; Zhong et al., 2021). REP has been used as an effective teaching method in engineering education, science education, and programming education (Dempere, 2009; Verner & Greenholts, 2017), due to it having achieved positive effects on students' learning motivation, problem-solving ability, critical thinking, logical thinking ability, design thinking, analytical skills, multi-tasking ability, and learning performance (Abdüsselam et al., 2022; Akerdad, et al., 2022; Ladachart et al., 2022; Liu et al., 2023).

Referring to the stage of reverse engineering, Wood et al. (2001) proposed a 10-step reverse engineering and redesign approach for college students that includes three stages: reverse engineering, modeling and analysis, and redesign. In the reverse engineering phase, the product is dissected. The actual function and shape of the product are explored. In this process, there are five steps to go through: investigation, prediction, hypothesis, product disassembly, and experiment. The second phase is modeling and analysis. The purpose of this stage is to try to give students a full understanding of the design principles and parameters. The final stage is to redesign the product through three approaches: parametric, adaptive, and original. Ogot and Kremer (2006) proposed the Disassemble/Assemble/Analyze (DAA) framework that is also named dissection and reverse engineering. In the DAA framework, there are two dimensions: (1) teachers explain how to conduct DAA exercises to students orally or in writing. Students can answer some questions about "how equipment is put together" and "how equipment works." These activities are classified as dissection. (2) Engineering knowledge is necessary to complete DAA exercises. Students need to explain "Why is the product designed this way?" and "Why choose a particular material?" These activities are classified as reverse engineering. Huang (2007) indicated that product reverse engineering consists of three levels: (1) engineering theory (e.g., product design automation). (2) Technical tools. This level represents the reconstruction of the reverse design process. (3) Application system is a reverse engineering system for developing practical products. Kennedy et al. (2016) designated the reverse engineering process as comprising six steps: 1) estimating, 2) observing, 3) dismantling, 4) analyzing, 5) testing, and 6) documentation. Thayer (2017) suggested that the reverse engineering process includes five steps: 1) determining the design intent, 2) observing, 3) dismantling, 4) analyzing, and 5) redesigning. Tan et al. (2021) extended the DAA model proposed by Ogot and Kremer (2006) and introduced the DA^3D activity framework: 1) Dissemble: Dismantle the finished product into its components. 2) Analyze: Study the components. 3) Assemble: Piece every part back together. 4) Augment: Think about any other objects that use similar physical principles. 5) Design: What inspirations could be acquired from the design of the project, and what needs to be considered in the design (e.g., shape, size, and function)? Abdüsselam et al. (2022) proposed that reverse engineering has five steps: 1) preview, 2) question, 3) revise, 4) reflect, and 5) review.

The existing REP was proposed for providing guidance for higher education students; however, it is not suitable for K-12 students' robotics education. For example, the 10-step reverse engineering and redesign approach is scattered and lacks the process of comparison and reflection, which is not conducive to students forming a systematic and personalized robot education and teaching process. As a result, Zhong et al. (2021) proposed the REP model and categorized it into four pedagogical categories: (1) deconstruction and recovery pedagogy, (2) troubleshooting and recovery pedagogy, (3) elements mini-trim pedagogy, and (4) structural innovation pedagogy. These four categories can be used individually or in combination depending on the learning content and teaching stage. The first pedagogy is the decomposition and reduction process of robotic products. The second pedagogy is the process of analyzing and solving the malfunctioning robot. The third pedagogy is the process of decomposing robot products and making micro innovations. The last pedagogy is the process of decomposing a robot product and reconstructing its structure. This kind of REP is suitable for the robot education of primary school students. Thus, the current study used the REP model proposed by Zhong et al. (2021).

2.3. Purpose and research question

There is a consensus regarding the need to cultivate K-12 students' creativity, but the level of students' creativity is still unsatisfactory (OECD, 2019). Robot education is helpful to students' creativity (Guven et al., 2022; Yang et al., 2020; Zhang & Zhu, 2022). However, teachers seldom take corresponding measures to cultivate students' creativity in the curriculum, but pay more attention to the achievement of students' learning goals (Karwowski et al., 2020). SCAMPER offers several strategies for promoting student creativity (Gu et al., 2022; Rahimi & Shute, 2021). REP that explores an existing product for redesign has some similar views to SCAMPER, and has a positive effect on cultivating students' creative self-efficacy in robotics education (Zhong et al., 2021). However, showing a product to students may fix their thoughts and inhibit their creativity (McLellan & Nicholl, 2011; Schut et al., 2020). Thus, the applicability of REP to cultivating students' creativity in primary school robotics education needs to be explored. To gain a more thorough understanding of individuals' creativity, creative self-efficacy, creative thinking, and robotic creative products were all used as indicators of students' creativity. In addition, PBP is currently the most commonly used teaching method in robotics education (Darmawansah et al., 2023; Sun et al., 2022). The following research question was therefore proposed to guide this study:

RQ: Does reverse engineering pedagogy (REP) facilitate primary school students' creativity better than project-based pedagogy (PBP)?

3. METHOD

3.1. Participants

A quasi-experimental design was conducted in this study, using a pre-test and post-test non-equivalent control group design to collect data (Shadish et al., 2002). This research took place in a public primary school in Xiamen city, China. Two intact classes were randomly selected from the fifth-grade classes of the same primary school taught by the same teacher in the same lab. This teacher has rich experience in robot teaching and leads primary school students to participate in the Youth Robot competition held by the region every year. Therefore, this teacher was willing to participate in the research and to reform her curriculum. Several policies and measures have been adopted by the Chinese Ministry of Education to introduce robotics to primary and secondary schools and to establish courses that focus on educational robot design, construction, and programming. Students are exposed to programming and learning robotics from the fifth grade in primary school. This study was conducted with the existing classes as intact groups, so the subjects could not be randomly assigned to the intervention or control group in order to reduce interference to the school and improve the ecological validity (Seel, 2012). Therefore, one class was assigned as a control group (CG), and another was assigned as an intervention group (IG). The CG had 46 students (24 boys and 22 girls) who received PBP, and the IG had 45 students (22 boys and 23 girls) who received REP. The CG and IG students were enrolled in the fall and were in their first semester of the fifth grade. The age of the two groups of students ranged from 10 to 11 years old.

3.2. Ethics and permissions

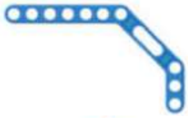
Parents of the children who participated in this study signed an informed consent form that was used to inform them that their children would be taking part in a research project and to obtain their consent. In addition, the children filled out the pre- and post-questionnaire voluntarily. The children were also assured that their responses to both the pre-test and post-test would not affect their course grades or any evaluation. This study was granted approval by the ethical committee of the author's university (approval code: NNU202209001).

3.3. Learning materials

A total of six learning activities from the students' artificial intelligence textbooks were selected in this study, namely (1) The Big Mouth of the Hippo, (2) The Eyes of the Cat, (3) The Talking Elephant, (4) The Wagging Tail of the Puppy, (5) The Wings of the Bird, and (6) The Long Neck of the Giraffe. As shown in Appendix Table 1, there were six robotic creative products. The robot kit used in primary schools is the uKit Robot Kit, and the open-source software is called UBTECH. UBTECH is Scratch-like graphical programming software customized for the uKit Robot Kit. The uKit Robot Kit was used by both groups; it comprises a controller and steering gear, fasteners, decorative pieces, connectors, and data cables. Take "The Wagging Tail of the Puppy" as an example to introduce the students' learning material. Table 1 shows the materials list for "The Wagging Tail of the Puppy." The goal of this learning topic is: (1) Make a puppy out of blocks. (2) The puppy will wag its tail, make a doggy bark, and blink its eyes. To achieve this result, the building blocks are used to build the shape of a dog (see Fig. 1). Learners use block programming to set the steering gear code. Moving (setting the rotating steering gear... degrees, duration... milliseconds), display (play sound...; show an expression...times), and control (wait for... milliseconds) code allows the dog to wag its tail, bark, and blink (see Fig. 2).

Table 1
The materials list of "The Wagging Tail of the Puppy".

Name	Picture	*N*	Name	Picture	*N*
Controller		1	Red connection pin		14
Switch		1	Square block		5
Steering gear ID-01		1	Deviator		7
LED		2	3*3 Connection block with hole		4

Bluetooth		1	2 times square block (grey)		10
120mm wire		4	special-shaped I-block		6
Switch wire		1	3*7 Double Angle beam		1
3*5 Curved beam		4	5*5 Connection block with hole		4
2*3 Bidirectional right angle beam		1			

Note. N represents the number of pieces.

Figure 1.
A dog robot constructed via the uKit Robot Kit by students.

Figure 2.
The code of the dog robot.

3.4. Interventions

The intervention procedure is shown in Fig. 3. The intervention lasted for one semester (16 weeks), with the 1st and 16th weeks used for the pre- and post-surveys, and the 2nd to 15th weeks for a 45-minute instructional session each week. The 2nd to 3rd weeks were used to introduce basic robotic knowledge and the programming software to the students. Pre- and post-surveys included the Torrance Tests of Creative Thinking Figural (TTCT-Figural) and creative self-efficacy scale. In the second and third weeks, two instructional sessions were arranged to teach the two groups of students the basics of robotics, the components of the uKit Robot Kit, and the function of UBTECH. In these instructional sessions, students learned how to use the robot kits (see Fig. 4) and how to express their creative ideas using mind maps. The CG and IG students learned how to build and program their robots around the learning subject for 13 consecutive weeks. Both CG and IG students participated in the robot learning activities in groups of 5-6 students. Each group of CG and IG students was assigned by the teacher according to the result of the TTCT-Figural pre-test. For example, after ranking the IG students (45 people) from high to low according to the total score of the TTCT-Figural pre-test, the IG students were divided into a matrix of 9 (per row) * 5 (per column) in a serpentine way. Then, students in each column were taken as a study group to ensure that each group included students with high and low TTCT-Figural scores. The IG class consisted of nine groups with five members in each group. The CG class consisted of nine groups, all of which had five members except for one group with six members.

Figure 3.
The intervention procedure.

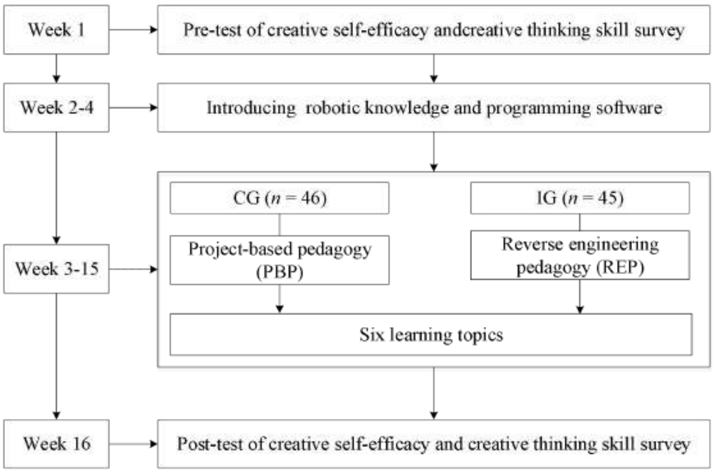
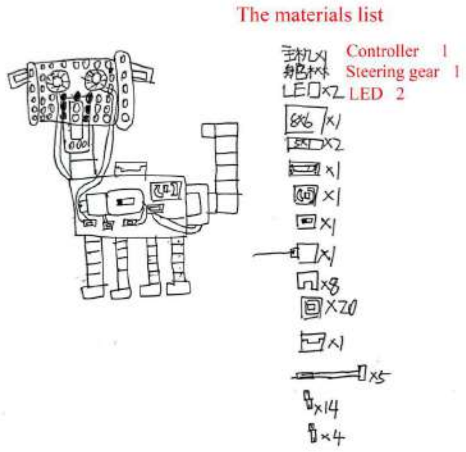


Figure 4.
Participants were familiar with robotic kits.

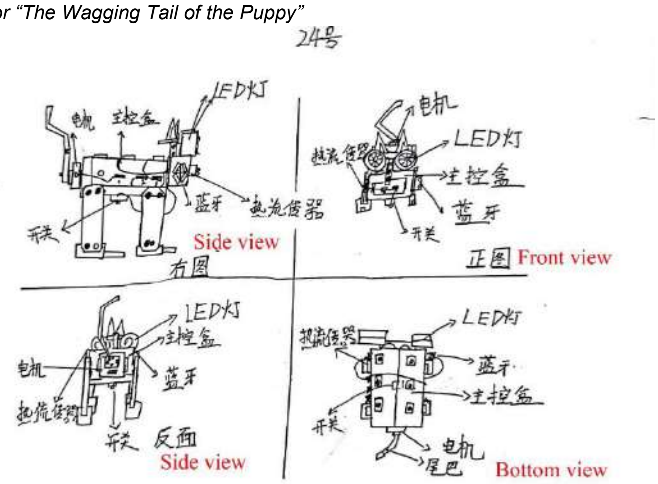
The teaching and learning procedures of the CG students who received the PBP intervention are as follows: (1) Creating an engaging learning environment that can stimulate students' creativity. In this stage, teachers use some images, animation, video resources, or concrete examples from daily life related to the learning topic to stimulate students' learning enthusiasm and reminisce about their past learning experiences. Then, the instructor explained the new concepts and techniques to the students. (2) Analyzing tasks and producing robotic designs. Students were encouraged to analyze and decompose the components of the robot model by drawing a flow chart and exploring more possible solutions. CG students' robot design plan for "The Wagging Tail of the Puppy" is shown in Fig. 5. (3) Constructing robot models. Students were required to complete some difficult tasks to build a block kit. The teacher guided students through video demonstrations or hands-on demonstrations. (4) Creating computational projects. Students were required to complete the writing tasks, test, and debug the programming according to the set tasks. Students may experience some difficulties in this process, such as unsuccessful code debugging. The teacher needed to guide students to reflect. (5) Engaging in extensible tasks and activities. Students were encouraged to innovate based on existing works to achieve higher-difficulty tasks. The teacher provided more examples related to the topic to stimulate students' creative works. (6) Sharing, Evaluating and Reflecting. Students presented their creative works. Students from other groups made evaluations. Finally, the teacher provided a conclusion.

Figure 5.
CG student's robot design plan for "The Wagging Tail of the Puppy".



The REP model proposed by Zhong et al. (2021) has four categories: (1) deconstruction and recovery pedagogy, (2) troubleshooting and recovery pedagogy, (3) elements mini-trim pedagogy, and (4) structural innovation pedagogy. This pedagogy can be used individually or comprehensively, and needs to be used in combination with the specific teaching situation. In the current study, the teaching and learning procedure of IG students who received the REP intervention was as follows: (1) Creating an immersive learning environment that can stimulate students' creativity. The teacher used some images, animation, video resources, or specific examples in life related to the learning topic to stimulate students' learning enthusiasm. The teacher explained new concepts and techniques to the students. (2) Disassemble the finished robot. In this process, students broke down the robot into its components and empathetically thought about the original design ideas. They needed to figure out: What components is this robot comprised of? Why are different components connected in this way? Students were encouraged to express their robot design ideas by mind mapping. IG students' robot design plan for "The Wagging Tail of the Puppy" is shown in Fig. 6. (3) Constructing robot models and generating innovative ideas. Students used the uKit Robot Kit to construct the robot's appearance. Students also needed to think about whether the robot could be innovated in appearance (shape or size) and functionality. (4) Create the computation project. Students were required to complete the writing task, testing, and debugging of the program according to the set task. The teacher needed to guide students to solve coding errors. (5) Sharing, Evaluating and Reflecting. Students built on existing works by innovating the functions of the robot to achieve higher-difficulty tasks. Students presented their creative work. Students from other groups made evaluations. Finally, the teacher provided a conclusion.

Figure 6.
IG student's robot design plan for "The Wagging Tail of the Puppy"



3.5. Instruments

Considering the multiple facets of creativity (Acar et al., 2022), at least two measurements need to be adopted to evaluate students' creativity (Kim, 2006). Therefore, in this study, creative self-efficacy, Torrance Tests of Creative Thinking, and robotic creative products were used to comprehensively evaluate students' creativity.

3.5.1. Creative Self-Efficacy Scale

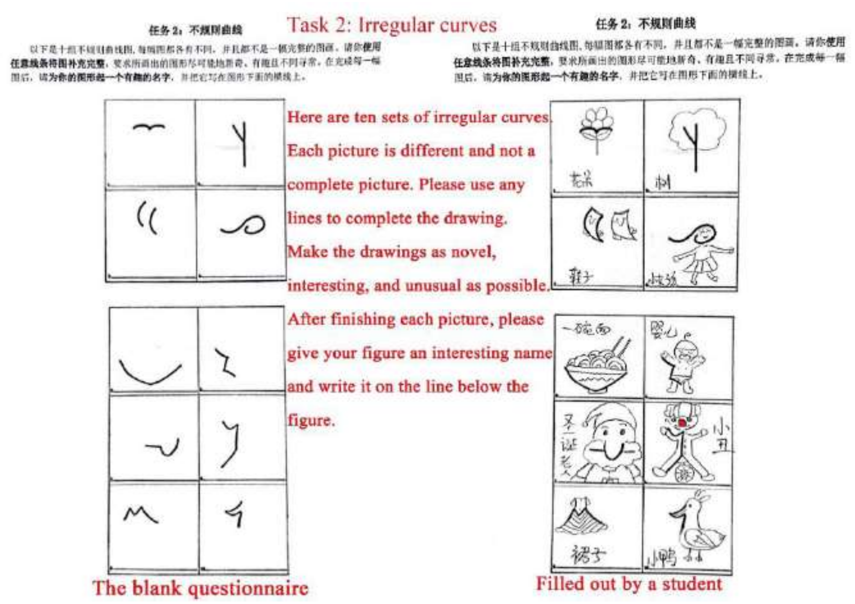
Creative self-efficacy refers to a personal belief that one can generate novel ideas and related solutions (Tierney & Farmer, 2002). A person with high creative self-efficacy is more likely to succeed due to tending to try various ideas and approaches to solve the task when facing an obstacle while performing a task (Kong et al., 2018). The creative self-efficacy scale was adapted from the scale proposed by Kong et al. (2018) which has good reliability (Cronbach's α = .822). It has four items to evaluate Chinese primary school students' creative self-efficacy level. An example item is: "It is important to be creative when you are programming." In this study, the obtained Cronbach's α was .90 in the pre-test.

3.5.2. Torrance Tests of Creative Thinking Figural

Torrance Tests of Creative Thinking (TTCT) is a measurement tool for the creative process developed by Torrance (1966). TTCT is supported by various validity assessment data and thus has been most widely used in evaluating K-12 students' creativity (e.g., Ozkan & Topsakal, 2021; Su et al., 2021). TTCT has two forms: TTCT-verbal and TTCT-Figural. TTCT-verbal and TTCT-Figural are comprised of six subtests and three subtests respectively (Torrance, 1966). TTCT-Figural has been used widely due to being more effective and reliable (Kim, 2017). Thus, the Chinese version TTCT-Figural adapted from Torrance (1969, 1974) by Wu (1998) was used to examine CG and IG students' creative thinking in this study. Wu (1998) found that students' responses in terms of originality were easily influenced by cultural background. Therefore, they adjusted Torrance's original scoring rules by integrating the local culture of China. The Chinese version TTCT-Figural manual has been tested in many schools and has good measurement properties, with good interrater reliability (0.93 – 0.98) and good test-retest reliability of each subscale (0.34 – 0.6) (Pan et al., 2023; Wu, 1998). The TTCT-Figural has versions A and B; version A was used in this study. It comprises three tasks: 1) Picture Construction activity (act. 1): Students were asked to draw imaginative pictures that must include the egg-shaped color map that was provided; 2) Picture Completion activity (act. 2): Students needed to complete the 10 incomplete pictures according to their ideas based on the offered irregular curves, and name each picture; and 3) Parallel Lines test (act. 3): Children were asked to draw based on the offered parallel lines. The Picture Completion activity of the TTCT-Figural is shown in Fig. 7 (left). Fig. 7 (right) shows one student's completed post-survey TTCT-Figural test.

Thirty minutes was needed for students to answer the TTCT-Figural questionnaire, with every activity needing 10 minutes (Wu, 1998). Thus, the teacher told students to stop answering the current task and turn the page to answer the next task every 10 minutes. According to the scoring instruction of the Chinese version TTCT-Figural manual, four subscales including originality (act. 1, 2, 3), fluency (act. 2, 3), flexibility (act. 2, 3), and elaboration (act. 1, 2, 3) were the observed variables. Two research assistants scored the pre- and post-TTCT questionnaires of the IG and CG students independently. Before starting the scoring, the researcher had three discussions with the research assistants to help them familiarize themselves with the scoring rules in the TTCT-Figural manual. Then, 15 TTCT questionnaires were taken as examples and graded by two research assistants together to resolve the differences during ratings via discussion. Then, the two research assistants rated all the IG and CG students' TTCT- Figural questionnaires respectively, and they reached good agreement with an intraclass correlation coefficient (ICC) > 0.90 (originality = 0.987, fluency = 1.00, flexibility = 0.994, and elaboration = 0.992) (Koo & Li. 2016). The average score of the two raters' rating scores was used as the final score of the students on the TTCT-Figural questionnaire. Before summing up the score of the subscales to calculate the overall creativity score, the score of the subscales was converted into a T-score (Wu, 1998).

Figure 7
The picture completion activity of TTCT-Figural.



3.5.3. Assessment rubric of the robotic creative products

Creative products consist of two facets, namely usefulness and novelty (Plucker et al., 2004; Runco & Jaeger, 2012). The creative idea must actually solve and apply to the specific problem at hand, and be fleshed out in detail in terms of being exact, concise, and clear (Dean et al., 2006). In this study, robotic creative products were constructed by students using the uKit Robot Kit according to the learning themes and learning objectives. The assessment rubric of the robotic creative product was adopted from the robotic design project assessment rubric proposed by Zhong et al. (2021), that was designed to evaluate Chinese primary school fifth-grade students' robotic products and to consider the applicability of the robotic products. According to Zhong et al. (2021), the robotic product rubric consists of three sub-dimensions, namely "technology and methods" (5 points), "function and performance" (5 points), and "creativity and personality" (10 points). In this study, "creative and personality" was renamed "idea novelty" after discussing with experts who specialized in technical education and engineering education, due to this dimension being used to illustrate students' novel ideas. "Idea novelty" must be judged in relation to how unusual it is in the overall population of ideas or how unusual it is in the mind of the idea rater (Dean et al., 2006). Therefore, a creative robotic product's two facets consisted of (1) Usefulness (10 points). "Technology and methods" and "function and performance" were used to respond to students' useful ideas for solving a specific problem. Example items of "technology and methods" and "function and performance" are "Students can use robotic-related knowledge to design their product" and "After repeated testing, this product can still run stably" respectively. (2) Novelty (10 points). "Idea novelty" was used to observe how unusual students' robotic products were in the overall class. An example item is "This product is creative in technology, form, or function." Each subdimension has two items, rated in the range of "0" points (*strongly disagree*) to "2 or 3" points (*strongly agree*). For example, "function and performance" has two items: "robot products can fulfill the functions predetermined in the textbook" (ranging from 0 to 3 points) and "after repeated testing, this product can still run stably" (ranging from 0 to 2 points). Since the stability of robot operation can only be discussed on the basis of the realization of basic functions, the scores of the two items in the weight setting are different. The total score was the sum of the scores of the sub-dimensions. Two professors specializing in technical education and engineering education, and two elementary school teachers teaching information technology courses were invited to review the criterion scoring rules and to give feedback to improve them.

In this study, CG and IG students' educational robotics creative products were evaluated by the instructor and one researcher. The instructor was familiar with the teaching content and learning materials, and could effectively evaluate the students' robotic products. The researcher discussed with the instructor some students' new topic robotic product and design ideas online two or three times. This helped them reach an acceptable agreement when evaluating the students' robotic products, with an ICC of 0.78 (Koo & Li, 2016). Then, they scored all students' robotic products respectively.

3.6. Data analysis

SPSS version 25.0 (SPSS/PC; SPSS-25.0, Chicago, USA) was used to analyze the data. In addition, *t* tests, ANCOVA, and ANOVA were used to check whether there were differences in the creative self-efficacy, creative thinking, and student robotic creative products of the CG and IG students before and after the intervention, to evaluate the effectiveness of REP compared with PBP. Therefore, an independent sample *t* test was used to examine whether the CG and IG students had a similar level of creative self-efficacy and creative thinking before the intervention. The paired sample *t* test was used to test whether the CG and IG students' levels of creative self-efficacy and creative thinking were higher than before the intervention. In addition, Cohen's *d* was calculated to indicate the effect size. The values of Cohen's *d* between 0.2~0.5, 0.5~0.8, and 0.8 are considered as small, moderate, and large effects, respectively (Cohen, 1988).

The extraneous differences between IG and CG can be controlled by using ANCOVA (Hair et al., 2018). The pre-survey scores of creative self-efficacy and creative thinking were used as covariate variables to adjust possible pre-existing differences, and the post-survey score of creative self-efficacy and creative thinking were used as the dependent variable. ANOVA was conducted to know whether IG students' robotic creative products were better than those of CG students after the intervention. In addition, partial eta squared (η^2) as a relevant estimate of effect size in ANCOVA and ANOVA was calculated and reported. For interpreting partial η^2, values in the range of 0 ~ 0.05 are deemed small, between 0.06~0.14 are considered as medium, and 0.14 and higher are accepted as a large effect size (Alper et al., 2022; Cohen, 1992).

4. RESULTS

4.1. Analysis of the impact of REP on students' creative self-efficacy

A similar level of creative self-efficacy was found between the CG and IG before the experiment (t = -1.37, p > .05, Cohen's d = 0.30). Then, the paired sample *t* test (see Table 2) indicated that both the IG and CG students achieved significant progress in their creative self-efficacy, reaching a large effect size. Moreover, one-way ANCOVA was performed with the pre-survey score of creative self-efficacy as the covariate variable, and the post-survey score of creative self-efficacy was used as the dependent variable. As illustrated in Table 3, significant differences were observed in the creative self-efficacy scores of the CG and IG, and reached a large effect size (partial η^2 = 0.044).

Table 2.
The paired sample t-test result for creative self-efficacy.

Variable	Group	Pretest		Posttest		Paired *t* test	Cohen's *d*	diff.
		M	*SD*	*M*	*SD*	*t*		
Creative self-efficacy	CG	3.9	0.4	4.2	0.5	-2.19*	0.50	post > pre
	IG	4.1	0.5	4.4	0.5	-5.49***	0.71	post > pre

*Note. *p < 0.05, ***p < 0.001.*

Table 3.
One-way ANCOVA result of the creative self-efficacy of the CG and IG.

Variables	Group	*M*	*SD*	Adjusted mean	Adjusted SE	*F*	Partial η^2
Creative self-efficacy	CG	4.2	.5	4.2	0.1	4.03*	.044
	IG	4.4	.5	4.4	0.1		

*Note. *p < .05.*

4.2. Analysis of the impact of REP on students' creative thinking

The CG and IG students had a similar level of overall creative thinking before the intervention (t = -0.20, p > .05, Cohen's d = -0.04). Although the total creative thinking scores and three sub-dimensions (originality, flexibility, and fluency) of IG students were significantly higher than those of CG students (see Table 4), the discriminant validity of the traditional scoring criteria of TTCT has been criticized, especially the high correlations of fluency with originality (Acar et al., 2022; Atakaya et al., 2022). Summative originality (idea quality) could be confounded by fluency scores (idea quantity) (Forthmann et al., 2020). In addition, students tended to give answers that differed from a new pattern category which may belong to different pattern categories or involve a mixture of categories, thereby resulting in a high correlation between flexibility and fluency (Azaryahu et al., 2023). Therefore, there is a high overlap among originality, flexibility, and fluency (Kim, 2006; Said-Metwaly et al., 2020). In this study, proportional originality (dividing the originality score by fluency) and proportional flexibility (dividing the flexibility score by fluency) were calculated to determine an "originality per idea" score and a "flexibility per idea" score, in which the confounding effect of fluency was controlled (Forthmann et al., 2020; Rubenstein et al., 2022).

As represented in Table 5, the result of the paired sample t test indicated that the IG students achieved significant progress in fluency, proportional originality, and total creative thinking, but not in elaboration and flexibility. In addition, according to the one-way ANCOVA result (see Table 6), after controlling the fluency confound, significant differences were found between CG and IG students' fluency, but not their elaboration, proportional originality, proportional flexibility, or total creative thinking. In total, REP intervention can enhance students' creative thinking, but it cannot promote students' creative thinking more than the PBP intervention.

Table 4.
One-way ANCOVA result of creative thinking between the CG and IG (without controlling the fluency confound).

Variables	IG Adjusted mean	CG Adjusted mean	ANCOVA *F*	Partial η^2	Post hoc
Fluency	8.8	12.5	51.66***	0.37	IG > CG
Flexibility	16.4	24.8	71.97***	0.45	IG > CG
Originality	10.5	15.1	18.20***	0.17	IG > CG
Elaboration	6.3	5.6	0.63	0.01	IG = CG
Total	186.9	213.4	36.87***	0.30	IG > CG

*Note. ***p < .001*

Table 5.
The result of the paired sample t test on the IG students' creative thinking (controlling the fluency confound).

Variable	Pretest		Posttest		Paired *t* test	Cohen's *d*
	M	*SD*	*M*	*SD*	*t*	
Fluency	7.9	3.4	12.1	3.3	-8.15***	1.26
Elaboration	7.4	5.7	6.3	6.0	1.39	-0.19
Proportional originality	8.8	3.2	7.2	2.4	2.96**	0.57
Proportional flexibility	3.8	0.3	4.0	0.5	-1.91	-0.49
Total	177.0	18.5	153.6	21.5	7.30***	1.17

*Note. ***p < .001; **p < .01.*

Table 6.
One-way ANCOVA result of creative thinking between the CG and IG (controlling the fluency confound).

Variables	IG Adjusted mean	CG Adjusted mean	ANCOVA *F*	Partial η^2	Post hoc
Fluency	8.8	12.5	51.66***	0.37	IG > CG
Elaboration	6.3	5.6	0.63	0.01	IG = CG
Proportional originality	6.7	7.4	2.23	0.03	IG = CG
Proportional flexibility	3.9	3.8	1.91	0.03	IG = CG
Total	148.4	149.2	0.06	0.00	IG = CG

*Note. ***p < .001*

4.3. Analysis of the impact of REP on students' robotic creative products

To assess the students' performance in robotic creative products, one-way ANOVA was performed (see Table 7). Significant differences between the CG and IG students in the scores of the six robotic creative products were observed ($p < .05$), and the partial η^2 of the six products ranged from 0.045 to 0.063, achieving a small effect size. The findings indicate that IG students who received REP had better performance in finishing the robotic creative products than CG students who received PBP. Thus, REP can significantly enhance students' robotic creative products compared with PBP.

Table 7.
One-way ANOVA result in the scores of six robotic creative products between the CG and IG students.

Source	Group	*M*	*SD*	*F*	Partial η^2
Product 1	CG	14.8	1.0	4.21*	.045
	IG	15.3	1.2		
Product 2	CG	16.3	1.3	5.21*	.055
	IG	17.0	1.3		
Product 3	CG	15.8	1.3	4.53*	.048
	IG	16.4	1.4		
Product 4	CG	16.3	1.2	6.02*	.063
	IG	17.0	1.5		
Product 5	CG	16.0	1.3	4.29*	.046
	IG	16.6	1.3		
Product 6	CG	16.5	1.5	5.05*	.050
	IG	17.1	1.2		

*Note. *p < .05. The product represents a robotic creative product.*

5. DISCUSSION

The cultivation of creativity of K-12 students is still worthy of attention (Bolden et al., 2020; OECD, 2019; Ozkan & Topsakal, 2021; Yang et al., 2020). In the school education system, the specialized cultivation of creativity is not positively responded to by teachers (Karwowski et al., 2020; OECD, 2019; Patston et al., 2021; Rahimi & Shute, 2021), due to it occupying part of the teaching plan and teachers being more inclined to pay attention to whether students achieve learning goals (Karwowski et al., 2020). Thus, adjusting teaching strategies is a good choice to promote students' creativity (Chen et al., 2020; Xia & Zhong, 2018; Wu & Wu, 2020; Zhong et al., 2021). According to prior studies, REP, as a reverse project-based teaching method, can actively promote primary school students' creative self-efficacy (Zhong et al., 2021) and enhance students' learning performance, design thinking, and computational thinking (e.g., Abdüsselam et al., 2022; Akerdad, et al., 2022; Ladachart et al., 2022; Liu et al., 2023), but whether it can promote students' creativity needs to be further confirmed.

Therefore, a quasi-experimental study that utilized a non-equivalent groups design was conducted to ascertain whether REP facilitates students' creativity better than PBP, which is a widely used teaching method in the context of educational robotics learning activities (Darmawansah et al., 2023; Sun et al., 2022). Creativity can be understood in many ways; the creativity explored in this study was "mini-C"; that is, it has personal meaning and usefulness in the context of robotic activities (Kaufman & Beghetto, 2009). Creativity in robotics education supports students in exploring educational robots with different functional types by building and programming (Leroy et al., 2021).

Matching is a necessary condition for controlling the differential learning rates and discrimination abilities (George et al., 1964). According to the independent sample *t*-test, there were no significant differences in IG and CG students' creative self-efficacy and creative thinking before the intervention. In addition, IG and CG students were serpentine grouped according to TTCT pre-test results to ensure that each group of students consisted of both high and low levels of creativity. Regression to the mean (RTM) as a ubiquitous phenomenon in repeated data can be alleviated through ANCOVA and random allocation of the comparison group (Barnett et al., 2005). However, to reduce the interference to the school and to improve the ecological validity (Seel, 2012), the existing two classes were allocated as an intact IG and CG in the current study. ANCOVA was used to analyze the pre- and post-creative self-efficacy and TTCT-Figural to control the extraneous differences between IG and CG (Hair et al., 2018). The results of one-way ANCOVA showed that the IG students had higher creative self-efficacy than the CG students after the intervention, and reached a large effect. IG students' scores on the robotic creative products were better than those of the CG students, reaching a small effect size. Based on the TTCT-Figural, REP intervention can promote IG students' fluency, proportional originality, and total creative thinking, but not their elaboration and flexibility. Compared with CG students, IG students had significantly higher total creative thinking and its three dimensions (originality, flexibility, and fluency) after the intervention. Low elaboration scores are common in students' TTCT-Figural (Wu et al., 1988). The TTCT test requires students to consider all aspects of a solution in a limited time. Participants often strike a balance between the quality and quantity in each task, making it difficult for them to concentrate on an idea for elaboration (Briggs & Reinig, 2010). For example, Gonthier and Besançon (2022) found that some participants with low fluency scores spent a great deal of time on several ideas in the "picture completion activity" and "parallel lines test," but the level of elaboration was not high. Due to the fluency confound, the proportional scoring method was used to analyze the data of TTCT-Figural, and the results showed that IG students' creative thinking was not significantly higher than that of CG students. Referring to the four subdimensions of TTCT-Figural, there was a significant difference between IG and

CG students in fluency, but no significance was observed for elaboration, proportional originality, or proportional flexibility. Thus, REP did not show a significant advantage over PBP in terms of enhancing students' creative thinking. However, REP intervention can facilitate IG students' fluency, proportional originality, and total creative thinking, but not their elaboration or flexibility.

In sum, IG students' creativity was promoted after one semester of robotics activities that were taught via REP. Moreover, IG learners who received REP gained a higher level of creativity self-efficacy and generated better robotic creative products than CG students who received PBP. Our findings did not support the view that analyzing a complete product's functions and features may limit learners' creativity (McLellan & Nicholl, 2011; Schut et al., 2020), but corroborates the research of Zhong et al. (2021) regarding the positive effect of REP intervention on primary school students' creative self-efficacy. The findings also resonate with the result of Tan et al. (2021), showing that REP can provide ways for students to generate fluent ideas.

The core difference between REP and PBP is students' learning process. Differing from the CG students receiving PBP learning who were not exposed to the completed educational robot first, but finished the task according to the learning objective step by step (Ladachart et al., 2022; Zhong et al., 2021), the IG students receiving REP needed to analyze the composition of an already formed educational robot and its programming code to experience the original design intention and grasp the key factors of design characteristics through observation and disassembly (Akerdad, et al., 2022; Liu et al., 2023; Vukašinović & Duhovnik, 2019; Zhong et al., 2021). For students who are new to design, if they can understand the intention of original design from disassembly and learn to deal with conflicts with peers in the design process, they may obtain efficient and meaningful methods to engage in design activities (Ladachart et al., 2022). Moreover, the disassembly and assembly of educational robots required the students' hands-on operation that enabled them to have a deeper understanding of the design intention of the original robot, transfer the learned knowledge to their daily life, and eventually turn it into micro-innovation products (Bertoni, 2019; Lur et al., 2022; Plaza et al., 2018).

IG students needed to think about the relationship among various components. Different understandings of the relationship between components helped them make micro-innovative products with new functions or slightly changed appearance or coding function under the guidance of the teacher (Bertoni, 2019; Lur et al., 2022; Wood et al., 2001), thus increasing the students' creative self-efficacy (Atwood-Blaine et al., 2019; Zhong et al., 2021). For example, in the learning topic named "The Wagging Tail of the Puppy," the original robot dog could only perform the following function: "The robot dog wagged its tail, then barked, and finally blinked once." In comparison, the IG students' micro-innovative robot dog could perform the function as follows: "The dog barks, blinks, and slowly wags its tail from side to side" and "barks three times, blinks its eyes and swings its tail from side to side." The IG students needed to systematically search the knowledge system related to the learning task within the prescribed time based on fact finding, propose different problem solutions and discuss them with team members, evaluate the most creative ideas that fitted the learning task, and apply their creative ideas to the robot activities. The process of finding the most creative ideas by searching for relevant knowledge to acquire solutions is also beneficial to students' creative results (Barak, 2013; Van Hooijdonk et al., 2020). It also stimulated IG students' creative self-efficacy (Zhong et al., 2021). Thus, REP could result in learners' better creativity in robotic education than PBP.

6. CONCLUSION AND IMPLICATIONS

The present study explored whether REP is helpful for the cultivation of students' creativity in primary school students' robot education compared with PBP. The results showed that students who were taught with REP performed better on creativity self-efficacy and robotic creative products compared to those who learned with PBP, but not on creative thinking. Theoretically, the findings of this study further prove the possibility of using REP for the cultivation of primary school students' creativity in robotics education. Practically, this research was carried out in an authentic teaching environment, which provides some reference for the specific practice of robot education. Robotic activities learning design needs to offer students existing knowledge of the immersive experience for coping with robots and visual-programming activities that support them in being aware of original design ideas and generating new ideas, then constructing their knowledge. By disassembling and assembling educational robots to participate in such learning experiences, students can gain a deeper understanding of the programming concepts.

7. LIMITATIONS AND FUTURE WORK

Some limitations should not be neglected. First, although the students in the two classes were taught by the same instructor, and the level of two classes' creative thinking was similar before the intervention, there may still be some potential factors that could have interfered with the results of the intervention. For example, there is a gender difference in enhancing elementary school students' creativity (Noh & Lee, 2020). In this study, grouping was based on TTCT-Figural pretest scores. It was difficult to ensure that the gender ratio in each group was the same in the final grouping result. The skewed gender distribution may have influenced the results and limited the generalizability of our findings. Therefore, to strengthen the findings of this study, future studies using non-equivalent control designs can consider measuring a rich set of pretest predictors of outcome and carefully match them with a stable covariate to obtain approximately randomized designs (Shadish & Cook, 2009). If any other intervention conditions are allowed, future studies could consider selecting subjects based on multiple measurements and randomly allocate the comparison group to alleviate RTM. Secondly, whether REP can play the same role in a larger sample from different grades and regions is a question. These problems need to be explored in the future.

Thirdly, this study only collected students' creativity self-efficacy, TTCT-Figural questionnaire data, and robotic creative products to interpret the effectiveness of reverse engineering teaching pedagogy compared with PBP. The confusion between fluency and originality has been widely discussed in TTCT. The proportional scoring method can be useful to solve the fluency confound problem, but tends to lead to weak reliability (Acar, 2023; Acar et al., 2022), and does not reward those who are more flexible or original overall (Acar et al., 2022; Runco & Acar, 2012; Runco et al., 1987). The fluency confound problem results from the combination of specific scoring procedures and task structures in TTCT (Acar, 2023). In addition, it is difficult to form a unified assessment rubric to evaluate educational robot products that are easily affected by the learning context. Therefore, more measurement tools can be used to measure students' creativity using both qualitative and quantitative methods. From the perspective of research design, future research can use the interview method to obtain students' experience of REP and help educators and researchers understand its implementation effectiveness. For example, students' learning behavior difference during robot building could be captured and explored further via the learning behavior analysis method so that specific behavioral differences could be observed.

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10.CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Xiaohong Liu: Conceptualization, Methodology, Formal analysis, Visualization, Investigation, Writing – original draft, Writing – review & editing. Jianjun Gu: Conceptualization, Methodology, Funding acquisition, Supervision. Li Zhao: Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

11.DECLARATIONS OF COMPETING INTEREST

Authors declare that they have no conflict of interests.

12.DATA AVAILABILITY

Data will be made available on request.

13.ACKNOWLEDGEMENTS

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14.APPENDOIX 1

A brief introduction of the six robotic creative products.

Learning activities	Learning goal	Robotic product	Programming code for the steering gear
(1) The Big Mouth of the Hippo	Build a hippo out of blocks. Use the steering gear and programming code to make the mouth of the hippo open and close.		
(2) The Eyes of the Cat	Build a cat out of blocks. The LED component is used to make the cat's eyes open and light up and close.		
(3) The Talking Elephant	Build an elephant out of blocks. Move the elephant's trunk up and down or from side to side. Let the elephant make a sound when it wiggles its trunk.		

(4) The Wagging Tail of the Puppy	Make a puppy out of blocks. The puppy will wag its tail, make a doggy bark, and blink its eyes.		
(5) The Wings of the Bird	Make a bird out of blocks. After clicking the bird's back, the bird's wings wave once. After double clicking on the bird's back, the bird blinks three times.		
(6) The Long Neck of the Giraffe	Make a giraffe out of blocks. Set the angle of the code in the steering gear to allow the giraffe's long neck and head to move naturally. The giraffe can blink its eyes at this time. Finally, using Bluetooth audio, let the giraffe make a sound.		

Integrating Computational Thinking and Biology

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Abstract

Integrating computational thinking with biology can create new opportunities in education. A group pf pre-service teachers instructed a weeklong unit at a local high school that showcased a successful interdisciplinary approach. The pre-service teachers from technology and engineering education and biology education collaborated to implement the "Planter Pal" unit in a computer science class. The goal of the Planter Pal unit was for students to design a system using a Micro:bit, sensors, and an OLED screen to indicate whether a plant has sufficient water. Additionally, students personalized their Planter Pal using art materials, transforming the plants' pot into class pets. This integration of technology, biology, and design not only engaged students but also demonstrated an example of interdisciplinary teaching methods. This paper examines the instructional outcomes of this initiative, highlighting reflections of incorporating interdisciplinary projects in the classroom.

Key Words (Provide between 3 and 5 key words): Computational Thinking, Computer Science Interdisciplinary, Education

1. INTRODUCTION

Given that computational thinking (CT) is a fundamental aspect of modern STEM fields and permeates various disciplines (Henderson et al., 2007), integrating CT into K-12 education can open new opportunities for students. CT provides a structured approach to problem-solving applicable in both academic and real-world contexts, and even in everyday activities such as making a sandwich or brushing teeth (Henderson et al., 2007). Due to computational thinking occurring in everyday life, educators can incorporate CT into their pedagogical strategies within many subjects. Some authors argue that introducing CT in pre-college education enhances understanding and interest in Computer Science (CS) and STEAM (Science, Technology, Engineering, Arts, Mathematics) fields by improving perceptions of programming and problem-solving using CS concepts (Herrero-Álvarez et al., 2024). Therefore, K-12 curriculum designers have prioritized fostering CT skills (Grover, 2022). A strategy with potential involves broadening CS education for all students by training educators to incorporate CT into their current teaching subjects. By integrating CT into established teaching methods and subject areas, students can engage with CT practices and create computational models (Yadav & Berthelsen, 2022).

In 2016, the K-12 Computer Science framework was introduced to guide the development of standards, curricula, professional development, and the integration of computer science (CS) in primary and secondary education (Yadav & Berthelsen, 2022). This framework emphasized the importance of incorporating core computational thinking (CT) practices, such as abstraction and modeling, across the disciplines of CS, science, engineering, and mathematics. It highlighted the need to clarify CT's role within these disciplinary contexts and its relationship to CS and coding in K-12 classrooms (Yadav & Berthelsen, 2022). Given the ongoing uncertainty about how CT fits within various subjects and its connection to CS, it is crucial to explore how and where CT can be effectively integrated into K-12 education. The "Planter Pal" unit serves as a practical example of this integration. Implemented by pre-service teachers from technology, engineering education, and biology backgrounds, this interdisciplinary unit merged technology, biology, and design in a computer science class. Students used Micro:bit devices, sensors, and an OLED screen to create systems for monitoring plant health and personalized their projects with art materials. This approach not only engaged students but also demonstrated how interdisciplinary teaching methods can effectively incorporate CT into the curriculum. By examining the instructional outcomes of the Planter Pal unit, this paper aims to highlight some reflections of such integrative approaches in K-12 education.

2. CURRICULUM CONTEXT

When collaborating on the development of this curriculum, the three pre-service teachers from different disciplines worked to articulate their perspectives on knowledge and ideas pertinent to their subjects in relation to the unit's objectives (Rasch, 1994; McGehee, 2001). This helped ensure clarity regarding each teacher's contributions to the planning process and the development throughout the creation of the unit and its implementation (McGehee, 2001). During planning, the focus was on integrating biology, computer science, and technology education, enabling the three teachers to implement aligned lessons and strategies (McGehee, 2001). The pursuit of problem solving through design served as a shared objective that engaged the students (McGehee, 2001). This approach encouraged active engagement within each discipline, fostering genuine interaction and interdependence (McGehee, 2001).

In this project, three pre-service teachers divided the responsibilities for implementing this interdisciplinary unit over one and a half weeks in a computer science-oriented classroom at a local high school. The botanical components necessary for the project were supplied by a faculty member from the same school. Two of the students were pre-service technology and engineering educators, while the third was a pre-service biology teacher. The goal of the Planter Pal Unit was to integrate computer science, computational thinking, and biology, representing a fusion of the teachers' disciplinary backgrounds while aligning with the classroom's existing learning goals. Below is an outline of the unit:

OVERVIEW	Students will participate in a five-day unit focused on coding with micro-bits to monitor plant health. This lesson, designed for a computer science classroom, will integrate key biological concepts. Through this unit, students will explore the parallels between natural and artificial inputs and outputs by developing solutions to common problems. Specifically, they will investigate how understanding micro-bits and the inputs and outputs of cellular respiration can help them design solutions to prevent overwatering or underwatering plants.
LEARNING OBJECTIVES	**Overarching Unit Objectives:** 1. Students will code and assemble a fully functional and accurate Planter Pal device equipped with at least two sensors. 2. Students will develop a practical solution to a problem, demonstrating the integration of biology and computer science concepts. **Lesson 1 Objectives:** 1. Students will be able to collect data about their plant and learn about moisture sensors. 2. Students will be able to communicate the information they discovered through a class discussion. 3. Students will be able to brainstorm and sketch different LED configurations with their group that will be displayed on their micro-bit. **Lesson 2 Objectives:** 1. Students will be able to correctly explain one real world example of the Universal Systems Model. 2. Students will be able to develop a model that illustrates the Universal Systems Model in plant processes. 3. Students will be able to evaluate other students' prototypes by providing at least one student with constructive feedback. **Lesson 3 Objectives:** 1. Practice using block code to create a working code for a micro-bit 2. Compare the inputs and outputs of plants and micro-bits using Micro:bit water and light sensors 3. Students will explain the connection of the Universal Systems Model through both Science and Technology **Lesson 4 Objectives:** 1. Students will be able to break down the necessary steps needed to code their Micro:bit. **Lesson 5 Objectives:** 1. Students will be able to communicate their design ideas, final outcome, recognize difficulties, and justify design choices 2. Students will be able to provide constructive feedback on classmates' projects and plan

	iterations to improve their project 3. Students Relate the Micro:bit and Planter Pal to outside scenarios with relation to personal and local context
CAREER CONNECTIONS	1. Plant Biologists 2. User Interface (UI) Designer or Product Design Engineer 3. Agricultural Scientists/Agronomists 4. Plant Physiologists 5. Plant Biotechnologists 6. Software Engineers 7. Computer Hardware Engineers 8. Bioengineers
LESSON OVERVIEWS	
LESSON 1	Students will be engaged in information gathering around their specific given plant. They will explore to find information such as water intake of their plant, and the importance of moisture sensors. Students will then share the information they found about their plant to the class, where other students are encouraged to ask questions. Students will then be introduced to the Planter Pal design challenge. The teacher will then go over what a micro-bit is and show them an example and go through the Makecode website. The teacher will allow students sometime to explore the website, and then will give the students time to brainstorm the different symbols they might want to display on their Micro:bit. The teacher will then show a video of how mouser sensors are used for large scale farming. The teacher will end class by having students fill out an exit ticket, and then pack up for their next class. The overarching question that students will be exploring is are plants systems?
LESSON 2	Students will be able to apply the engineering principle of the Universal System model to plant processes like cellular respiration. Students will then be able to develop a prototype that solves a real-world issue and present it to the class. The design problem is to develop a soil moisture sensor to present at a local farming event to improve crop yields and make farming more efficient. This will allow students to step into the shoes of a biological engineer and begin thinking about problems from a different perspective.
LESSON 3	Students will explore computational thinking through Micro:bit prebuilt games. Using this engagement, the class will discuss the code that makes the game and apply it to Universal Systems. Students will transfer this information to their own planter pal project and break down their work plan into steps. After work time, students will also analyze their progress and code functionality, making a work plan for the next lesson.
LESSON 4	Workday
LESSON 5	Workday

This project's objective is to design a device tailored to monitor and display a specific plant's health status. The final deliverable will include a functional device that can be inserted into a plant's soil to accurately determine and convey the plant's health status. This project provides students with an excellent opportunity to apply interdisciplinary knowledge and express creativity. By integrating principles from biology, electronics, and computer science, students can deepen their understanding of how different fields intersect to solve problems. The use of a Micro:bit, moisture sensor, and phototransistor require technical skills in programming and circuit design, while understanding the specific needs of the plant involves biological knowledge. Additionally, creating a clear and visually appealing legend for another person to read their plants health using design software allows students to explore graphic design principles. This blend of science, technology, engineering, art, and mathematics (STEAM) encourages students to think creatively and develop innovative solutions, enhancing both their technical and artistic skills. Students can personalize the plant's pot by adding their own artistic elements, such eyes and other elements of a face. This creative customization lets students express their individual artistic flair while enhancing the project's aesthetic appeal.

Figure 1.
Example Finished Planter Pal
Completed planter pal featuring the Micro:bit and components from an agriculture kit. This group named their plant 'Fred'".

The unit is structured to last around a week and a half, focused on coding with micro-bits to monitor plant health, integrating computer science and biology concepts. Students will explore natural and artificial inputs and outputs, learning how to design solutions to prevent overwatering or underwatering plants. Throughout the unit, students will code and assemble a Planter Pal device equipped with sensors and develop practical solutions that merge biology and computer science. Lesson 1 involves gathering information about plant moisture needs, learning about moisture sensors, and brainstorming LED configurations for the micro-bit. In Lesson 2, students apply the Universal Systems Model to plant processes, develop prototypes for soil moisture sensors, and present their designs. Lesson 3 emphasizes computational thinking through prebuilt Micro:bit games, which students then relate to their Planter Pal projects. Lessons 4 and 5 are dedicated workdays for students to finalize their designs, communicate their ideas, and provide feedback on classmates' projects. The layout of this unit progressively builds students' skills in implementing and coding sensors that integrating biology, computer science, technology concepts in a cohesive manner. Furthermore, coding the Micro:bit helps students understand computational thinking as they see how the steps in their code will work in relation to their Micro:bit, the sensors, and their plant. The dedicated workdays allow students to finalize their designs and provide peer feedback that can enhance their projects through collaborative learning and iterative improvements. This unit builds students' prior skills and knowledge of CS and worked to foster an appreciation for the intersection of technology, biology, and technology, while preparing them for future opportunities.

3. METHODOLOGY

While this paper is looking at instructional outcomes of an interdisciplinary lesson, Chappell (2007) explains that reflective practice allows teachers to monitor and engage with their own thoughts and actions. Reflection fosters self-awareness and ongoing evaluation of one's work, aiming to promote growth and independence. It highlights a teacher's maturity and competence (Bengtsson, 1995; Chappell, 2007) while also reinforcing the connection between reflection and teacher development. In the context of this paper, the instructional outcomes of teaching a computational thinking unit that integrates biology, computational thinking (CT), and computer science (CS), reflective practice plays an important role. By engaging in reflective practices, the teacher/researcher who implemented this unit can assess how effectively they integrated these disciplines and identify areas for improvement for future implementations. The reflection can enable teachers to refine their instructional strategies, enhance their understanding of how these fields intersect, and better support student learning.

4. INSTRUCTIONAL OUTCOMES

The instructional outcomes of the Planter Pal unit were multifaceted, targeting both hard and soft skills. The Planter Pal unit was integrated into a computer science classroom where Code.org was the primary instructional tool. The lessons taught by the author engaged the students, particularly one who had a keen interest in plants and possessed extensive knowledge about various species. This integration of coding and plant biology not only captured the students' attention but also provided a unique opportunity for them to apply their coding skills to a real-world context. Students demonstrated the ability to integrate biological concepts with computer science. By the end of the unit, the students could explain how the Universal Systems Model applies to both plant processes, such as cellular respiration, and technological systems, such as coding and sensor integration.

Students developed technical proficiency by coding and assembling the Planter Pal device using Micro:bit, moisture sensors, and phototransistors. They honed their skills with block code, collected and analyzed data, and coded their Micro:bit to match their plant's needs Students in this CS class had nearly four months of school before implementing this lesson, providing them with a substantial amount of prior knowledge in computer science. The cohort additionally had completed a 36-week CS course as a prerequisite to the class. Therefore, the students had been in their second-level CS class for approximately nine weeks at the time of this unit's implementation. While the coding aspect of the project was familiar to them, integrating sensors and connecting them to the biological aspects of plants was a new challenge. Since the key focus of this unit was on CT, students were encouraged to apply computational thinking principles to create their own Planter Pal that was capable of monitoring and maintaining the plant's health through coding and sensor integration. The students worked in their groups to devised practical solutions by designing and coding their Planter Pal devices to accurately monitor soil moisture levels. Throughout the unit, students engaged in collaborative learning, working in groups to brainstorm, design, and implement their projects. The students worked in groups where they communicated skills, ideas and responsibilities. The collaborative environment within the teams and in the classroom allowed for students to support each other through challenges and share approaches to their challenges. Furthermore, the project allowed students to express their creativity by customizing their Planter Pal devices and designing user interfaces. This aspect of the unit encouraged students to incorporate artistic elements into their projects, amplifying the intersection of technology and design. Additionally, the unit exposed students to various career paths, including plant biology, agricultural science, design engineering, computer engineering, and biological engineering. By seeing the real-world applications of their classroom activities, students could better understand the relevance of their learning and consider future career opportunities in these fields. Overall, the Planter Pal unit integrated interdisciplinary knowledge to create an environment where students could learn through hands-on and minds on activities.

In conclusion, the integration of CT within K-12 education, as demonstrated by the Planter Pal Unit, provides a multifaceted approach to enhancing students' problem-solving skills and interdisciplinary understanding. This unit showcased how combining biology, computer science, and engineering principles could engage students in meaningful, real-world applications. By leveraging pre-service teachers' diverse disciplinary backgrounds, the Planter Pal Unit allowed students to explore the intersections of natural and artificial systems, develop technical proficiency, and foster creativity through hands-on activities. The positive instructional outcomes, including the ability to connect biological processes with technological systems and the development of practical problem-solving solutions, highlight the value of incorporating CT into existing curricula. Furthermore, the unit's emphasis on career connections underscored the relevance of these interdisciplinary skills, preparing students for future opportunities in various STEM fields. Overall, the Planter Pal Unit exemplifies how integrating CT into K-12 education can create enriching learning experiences that equip students with the skills necessary to navigate and innovate within our increasingly computational world.

4. REFLECTIONS

Reflecting on the teaching experience of the Planter Pal unit reveals its significant impact on students' learning and skill development. The unit, which merged computer science with plant biology, effectively engaged students by leveraging their existing coding knowledge and introducing them to new challenges involving sensors and biological systems. The integration of Code.org and the Micro:bit device provided a hands-on approach that allowed students to apply computational thinking (CT) principles in a practical context. Observing the students' progress, it was clear that they not only gained technical skills in coding and data analysis but also enhanced their ability to connect these skills with real-world applications. The collaborative environment fostered teamwork, communication, and creative problem-solving, as students worked together to design and code their Planter Pal devices. Additionally, the unit's focus on interdisciplinary learning bridged the gap between biology and technology, helping students understand the Universal Systems Model and its relevance to both natural and artificial systems. However, while students briefly explored the idea of integrating biology into a computer science classroom, it remains unclear whether their perceptions of how computational thinking (CT) and computer science (CS) relate to subjects like biology influence how they view their own work. Conducting further research on how an interdisciplinary unit may influence students' perceptions of various disciplines could be an opportunity for further exploration. Overall, the Planter Pal unit demonstrated how integrating CT through an interdisciplinary unit can enrich students' educational experiences, fostering an understanding of how technical and creative aspects of problem-solving can intersect.

5. FUTURE DIRECTIONS

Building on the Planter Pal Unit, future directions could enhance the integration of Computational Thinking (CT) in K-12 education. Since this unit was initially implemented with three pre-service teachers, including one from a biology education background, future development could expand beyond biology and computer science to incorporate additional disciplines such as environmental science, chemistry, physics, and art. This interdisciplinary approach would allow students to explore a wider range of CT applications across various fields. Additionally, implementing this unit in different classroom settings, such as art classes, could provide insight into how students with diverse interests perceive CT and design in relation to computer science. Extending similar CT-integrated units into both rural and urban schools could also allow educators to assess the adaptability of such units across varied educational contexts.

Lastly, to build on the insights gained from the Planter Pal Unit, educators should consider several key factors when implementing similar CT-integrated units. First, a more interdisciplinary approach can enrich the learning experience by showcasing CT's versatility in multiple fields. Second, it's important to adapt the unit to diverse educational settings, ensuring students from various backgrounds and interests can engage meaningfully with CT. Teachers should also focus on curriculum alignment, resource availability, professional development, and student engagement when designing these units. By embracing these possible considerations, educators can continue to innovate in K-12 education, preparing students with the computational skills. Incorporating these strategies around integration of computational thinking can empower students to apply these skills across a wide range of disciplines and real-world contexts.

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Does Medium Matter? Exploring Validity in Paper and Digital Spatial Ability Tests in Secondary Education

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Abstract

Spatial ability has long been linked with success in science, technology, engineering, and mathematics (STEM) disciplines with evidence suggesting that higher spatial abilities at younger ages can be predictive of higher academic attainment within STEM degree areas. Over the past few years there has been an increased recognition of the need for the development of spatial abilities in technology education, and the importance of developing such skills within adolescents has since been identified as an explicit area of importance within Irish secondary school curricula. In response to this curricular need, work has been done to investigate the development of such skills through direct instruction in a secondary level setting to examine the feasibility and explore potential difficulties associated with such implementations. A key element to such research studies is the measurement of spatial skills through psychometric testing, yet some uncertainty remains around the medium of this testing and the validity associated with the various mediums. To date some work has been done to investigate this relationship within a third level context, but the transferability of these findings to a secondary level context is still unclear due to the difference in developmental stages between these student cohorts. This paper aims to provide clarity around the use of paper-based and digital spatial testing mediums within a secondary level setting in regard to validity, to inform the methodological decisions of a larger study and similar future research. The data presented in this paper forms part of a study investigating the development of spatial ability within Irish secondary level technology education. Secondary school students in Ireland completed spatial testing of the Purdue Spatial Visualisation Test of Rotations (PSVT:R) and the Paper Folding Test (PFT) in both paper-based and digital formats. Item response theory analysis was conducted on both the PSVT:R (consisting of 30 items) and the PFT (consisting of 20 items) to determine the validity associated with the testing medium. The results from this study provide initial insights around the use of such testing mediums within secondary level technology education research and offer suggestions for further investigation.

Key Words: Spatial ability, Psychometric testing, Validity, Item response theory

1. INTRODUCTION

The importance of spatial ability within STEM disciplines is well established with evidence suggesting that higher spatial ability in secondary school may be predictive of future success and participation within STEM programs (Wai et al., 2009). Much of the related research conducted has focused on the S, E, and M of STEM, with technology education only becoming more evident in recent years. Technology education, with its applied and often abstract nature, undoubtedly relies on the ability to visualise solutions that do not yet exist. To support such visualisation, the development of spatial ability is an area that cannot be ignored. The importance of such abilities in technology education is something that has been gaining recognition over recent years, with developments in Irish curriculum documents including spatial ability as an explicit part of technology subjects (NCCA, 2019). Research trends have also shown the increased interest in spatial ability within technology education, and the investigation of how it is developed (Buckley et al., 2022; Lane & Sorby, 2022).

Spatial ability research often looks at the development of such skills and uses psychometric testing to establish measures of spatial ability before and after an intervention or activity in order to assess any gains (cf. Atit et al., 2020; Benedicic et al., 2023; Buckley et al., 2019; Duffy et al., 2020; Maquet et al., 2023; Sorby et al., 2018; Sorby & Panther, 2020). Popular measures of spatial ability are that of the Purdue Spatial Visualisation Test of Rotations (PSVT:R) (Guay, 1976) and Paper Folding Test (PFT) (Ekstrom et al., 1976), which focus on the rotations factor and visualisations factor respectively. Although these psychometric tests are popular, throughout the literature the application of different test formats is still something of uncertainty with a lack of clarity about the potential impact of different test formats. Both tests were originally designed for use in a paper-based format, yet they have often been adapted for digital data collection. Veurink & Hamlin (2015) discuss an observed difference among test formats in the PSVT:R, with digital test takers scoring lower. This however is contrasting what was later found by Buckley et al. (2016) who did not observe any significant differences between formats. Dautle & Farrell (2023) examine format differences through a lens of exploratory factor analysis and also find no difference between versions. These studies examined differences in test performance when looking at total scores, and as such questions still remain about differences that may exist at an item level between test formats. To examine the tests on an individual item level, a different approach is required. Previous work has been conducted to examine the PSVT:R on an individual item level, through item response theory (IRT) analysis (Nevin et al., 2015), which offers a comprehensive view of each test item in terms of difficulty, discrimination, and guessing. This paper aims to investigate the use of digital and paper-based versions of the PSVT:R and PFT through item response theory analysis and explore any impact of test format on test validity.

2. METHODS

2.1. Approach and participants

This paper forms part of a larger study where a quasi-experimental study design was implemented to evaluate the impact of an explicit spatial skills intervention on spatial ability and its transfer to mathematics. The study was conducted across a group of 1592 transition year (TY: transition year is an optional year of study in upper secondary lever education where students engage with a more fluid curriculum and place more focus on work placements and experiential learning) students in Ireland aged 14-17 (M = 15.3, SD = 0.51). The participants completed spatial ability testing in the form of the PSVT:R (n = 1416) and the PFT (n = 1383) in either a paper-based or digital format using Google forms. Recruitment letters were distributed to schools by Oide – the primary organisation for teacher continuous professional development in Ireland – and expressions of interest were then collected from willing schools. Twenty-five schools around Ireland were chosen based on a number of factors to ensure that there was as little bias towards any one group as possible. These factors included single-sex or coeducational schools, school DEIS status which is an indicator of schools in lower socio-economic areas, school population, sex of the teacher, and location of the school. Ethical approval was provided by the research ethics committee in the Technological University of the Shannon: Midlands Midwest, Ireland.

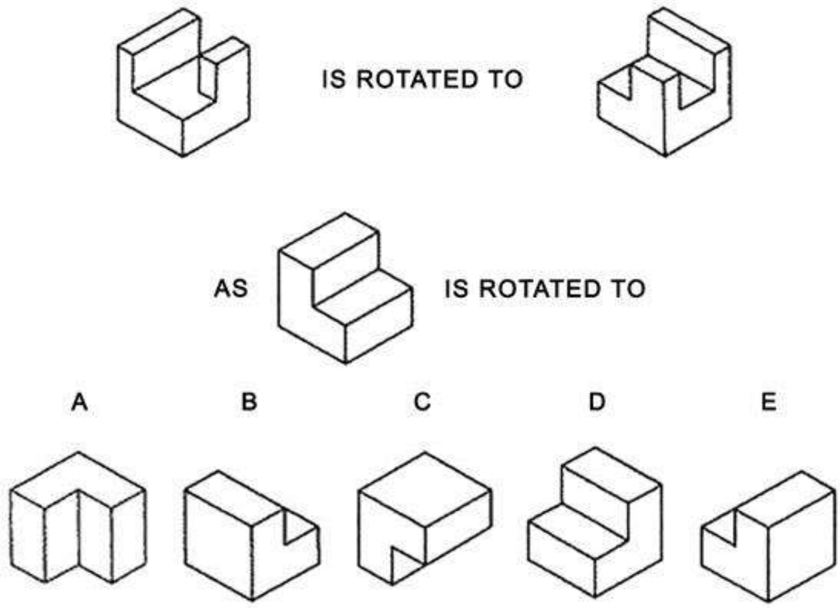
2.2. Data Collection

Participants completed testing either completely through a paper-based format, or completely through a digital format. Any differences in completion numbers for each test is due to student absenteeism, test completion errors, etc.

2.2.1. PSVT:R

The PSVT:R (Guay, 1976) was administered to all participants either digitally (n = 1162) or in a paper-based format (n = 254). This test was used to measure the rotations factor of spatial ability. The PSVT:R was scored out of 30 and participants were allocated 20 minutes to complete the test under the supervision of their teacher. An example item from the PSVT:R is shown below in Figure 1.

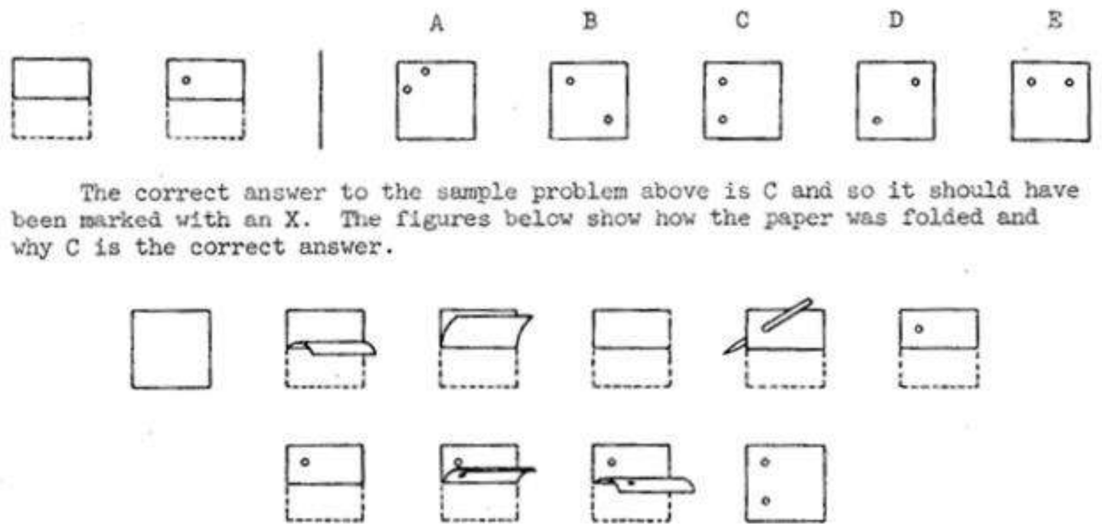
Figure 1.
Sample item of the PSVT:R



2.2.2. PFT

The PFT (Ekstrom et al., 1976) was administered to all participants either digitally (n = 1135) and in a paper-based format (n = 248). This test focused on the visualisation factor of spatial ability. The PFT was scored out of 20 and participants were allocated a total of 6 minutes to complete the test (2 x 3-minute halves) under the supervision of their teacher. An example item from the PFT is shown below in Figure 2.

Figure 2.
Sample item from the PFT



2.3. Analysis

Before conducting any analysis, the dataset was visually inspected and cleaned. Participants who completed any duplicate tests (n=71) were removed. Data analysis was completed with the use of RStudio (Posit Team, 2024). Descriptive statistics were first calculated, and basic visualisations were created to get an overview of the dataset and each variable. A descriptive statistics table was created using the psych (Revelle, 2024), dplyr (Wickham et al., 2023), and moments (Komsta & Novomestky, 2022) packages to inspect the mean, standard deviation, skew, and kurtosis of each variable within the dataset. Wilcoxon signed-rank tests were conducted using base R to examine any differences in test performance between formats.

As the main focus of this paper, IRT was conducted to examine how participants responded to items on both the PSVT:R and PFT, and to determine whether this was significantly different between paper-based and digital versions. Three-parameter logistic models were created for the IRT analysis to account for guessing within the test completion. The dplyr and mirt (Chalmers, 2023) packages were used to conduct the IRT analysis and the ggplot2 (Wickham et al., 2024) package was used to create the associated visualisations. Internal consistency testing was conducted with the psych package to further examine any differences between test formats.

3. RESULTS

3.1. Descriptive Statistics

Descriptive statistics for the PSVT:R and PFT can be seen below in Table 1.

Table 1.
Descriptive Statistics Table

Variable	N	Mean (SD)	Median (MAD)	Min	Max	Skewness	Kurtosis	Shapiro-Wilkes
DPSVTR	1162	13.41 (6.286)	13 (7.413)	0	30	0.369	2.527	W = 0.979, p < 0.05
PPSVTR	254	12.917 (6.023)	12 (5.93)	0	29	0.309	2.62	W = 0.982, p < 0.05
DPFT	1135	10.002 (4.26)	10 (4.448)	1	20	0.076	2.148	W = 0.979, p < 0.05
PPFT	248	9.379 (3.73)	10 (4.448)	2	19	0.002	2.427	*W = 0.983, p < 0.05*

Note: DPSVTR – Digital PSVT:R, PPSVTR – Paper PSVT:R, DPFT – Digital PFT, PPFT – Paper PFT

3.1.1. Internal Consistency

Internal consistency was calculated using Cronbach's alpha. Cronbach's alpha for the digital version of the PSVT:R was found to be α = 0.86 and the paper-based version of the PSVT:R was found to be α = 0.84 which was deemed to be an acceptable difference by the authors.

Cronbach's alpha for the digital version of the PFT was α = 0.82 and for the paper-based version of the PFT was α = 0.76 which suggests a slightly weaker level of reliability within the paper-based version, but this is still deemed an acceptable difference by the authors.

3.2. PSVT:R

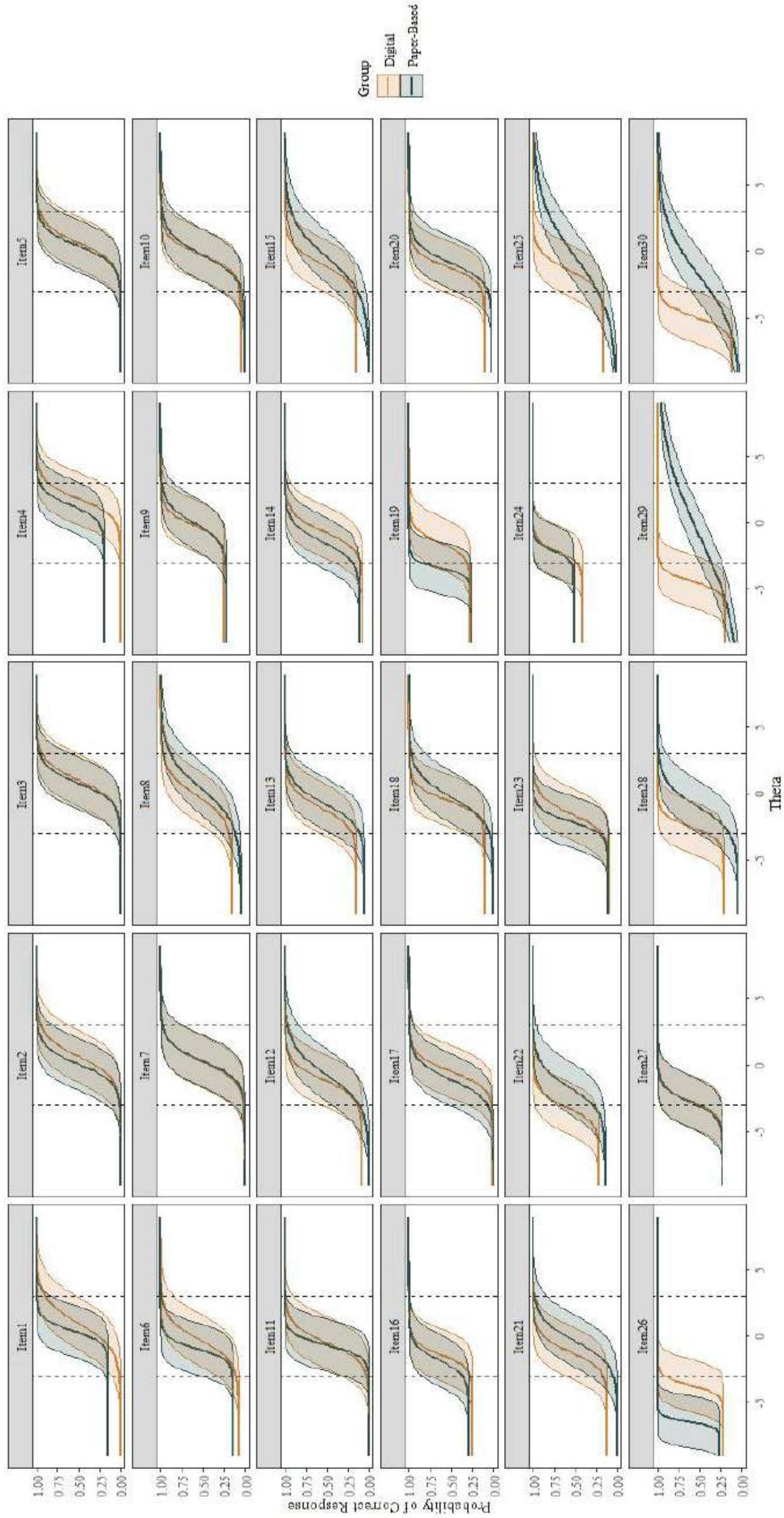
3.2.1. Group differences

As the variables were not found to follow a normal distribution, a non-parametric test was used to determine group differences on test performance. A Wilcoxon signed-rank test was conducted and no significant differences between paper-based and digital groups ($W = 153056$, $p = 0.353$) were observed.

3.2.2. Item Response Theory Analysis

Three-parameter logistical models were calculated for all items of the PSVT:R, grouped by test format, which can be seen below in Figure 3. Shading was added to highlight standard error at 95% confidence. Vertical lines were added at -3 and +3 theta which represent 3 standard deviations either side of the mean of the latent construct. From a visual inspection of the test items, it can be seen that although few test items were found to be extremely similar in nature (e.g. Item 3, Item 5, Item 7), confidence intervals of each group overlap for many of the test items between the vertical lines, highlighting that these are not significantly different from each other. There are however some exceptions to this which raise questions around the impact of test format. Item 4 shows an overlap between groups from -1 theta until around +3 theta where it then diverges, suggesting a significant difference between groups in the lower ability levels favouring paper-based test takers. A similar but reversed relationship can be seen with item 25 where the overlap stops at +1.75 theta and above showing digital test takers with the advantage. An interesting relationship also starts to develop with items 29 and 30, where they show no overlap from around -2.5 upwards, indicating that digital test takers have quite a significant advantage on these items across a range of ability levels.

Figure 3.
Item Characteristic Curves of the PSVT:R with 95% Confidence Intervals. Vertical lines are located at -3 and +3 theta.



Another interesting feature of this model is the probability shown on the y axis, which provides insight into the likelihood that a participant will choose the correct response at various ability levels. In a three-parameter logistical model such as this, guessing is taken into account and the model is adjusted as such. From a visual inspection of the figure, items were identified that showed high levels of probability at the low ability level (over 20% which is to be expected for 5-option items such as that of the PSVT:R), these were then refined by identifying their values at -3 theta. Potentially problematic items were extracted for further examination, these are shown in Table 2 below. A number of test items were found to have quite a high probability level which calls into question their difficulty level, and there also a number of items were the probability level varied quite a lot between test versions. When looking at the probability at -3 theta of all items in each test format, a significant difference could not be found ($t(56.069) = 0.951$, $p = 0.346$, 95% CI [-0.032, 0.088]), however a number of individual items have questionable differences between versions (e.g. items 19, 22, 28, 29, 30) which warrants further investigation.

Table 2.
Probability of choosing correct responses at -3 theta in the PSVT:R

Item	Percentage probability (rounded) with 95% CI	
	Digital Version	Paper Version
9	25%	23%
16	27%	37%
19	31%	85%
22	66%	30%
23	18%	21%
24	49%	55%
25	23%	23%
26	91%	100%
27	50%	53%
28	41%	14%
29	97%	36%
30	98%	37%

3.3. PFT

Group differences

A Wilcoxon signed-rank test was conducted, and no significant difference was found between paper-based and digital groups on test performance ($W = 151699$, $p = 0.054$).

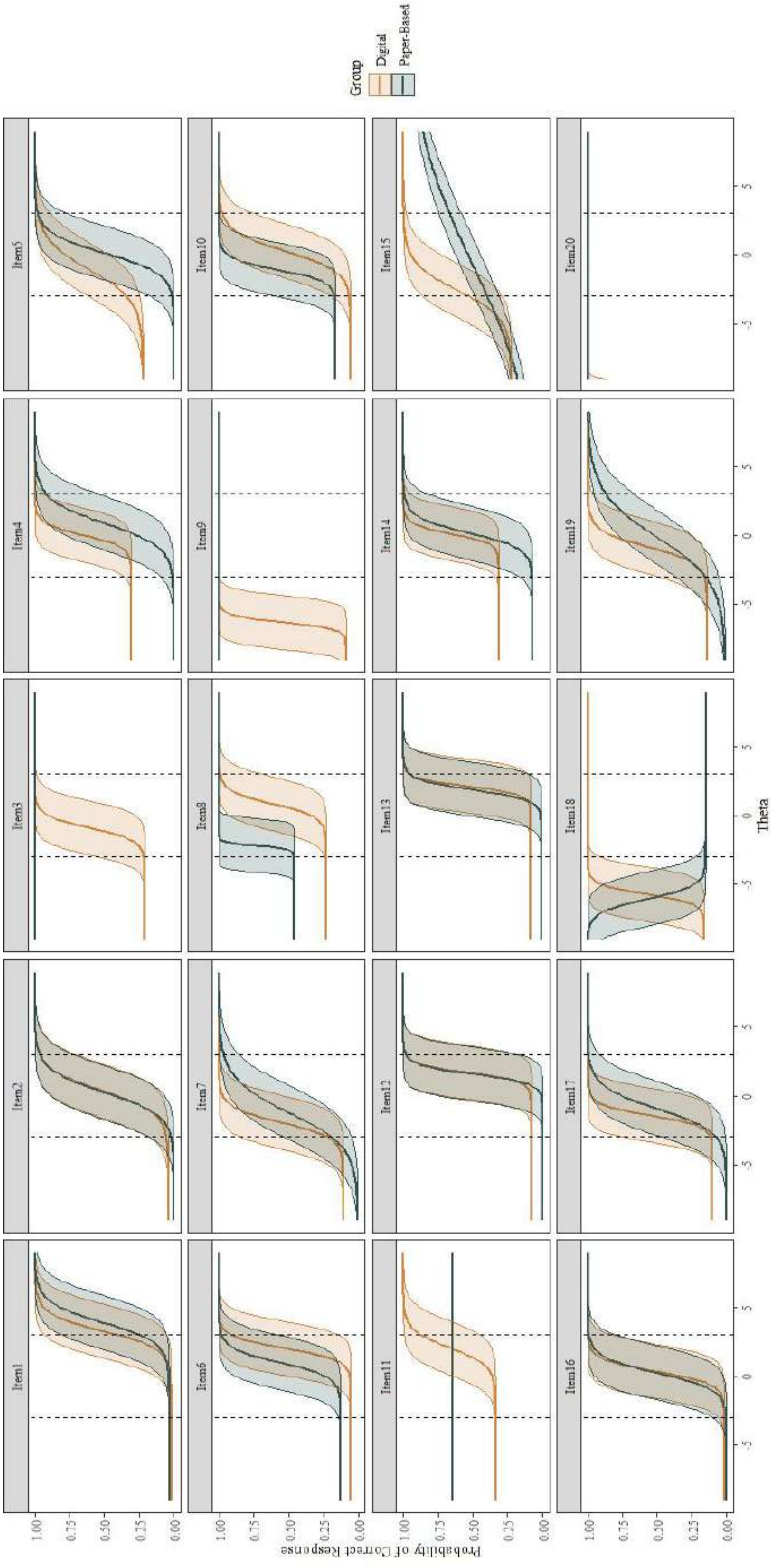
3.3.1. Item Response Theory Analysis

Three-parameter logistical models were calculated for all items of the PFT, grouped by test format which can be seen below in Figure 4. Shading was added to highlight standard error at 95% confidence, and as above vertical lines were added at -3 and +3 theta.

Similar to above with the PSVT:R, it can be seen from a visual inspection that there are many differences in the characteristic curves for each item, and there a number of these that are significant for at least a section of the curve. Item 3 shows a significant difference from around -0.3 theta downwards, item 6 from -2 downwards, item 8 from -1.5 downwards, and item 11 from 0 downwards all favouring paper-based test takers. Item 4 shows a significant difference from -1.75 theta downwards, item 5 from -2.5 downwards, item 12 from -1.25 downwards, item 13 from -1 downwards, item 14 from -2.3 downwards, item 15 from -0.5 upwards, and item 18 from -4 upwards all favouring digital test takers. Almost all differences discussed were evident at lower ability levels, indicating that participants with lower abilities are impacted more by test format. Other items can be seen to show differences also but only items with differences within the vertical lines were mentioned here.

Some other interesting relationships can be seen among certain items which appear to vary significantly from a typical characteristic curve S-shape (e.g. Items 3, 8, 9, 11, 12, 13, 15, 18, 20). Looking at item 3 it appears that no matter what the participants ability level, they had 100% probability of choosing the correct response if they completed the test on paper, whereas this relationship did not exist for digital test takers. A similar situation can be seen for item 9 and item 20, but in these cases the test format did not matter (except for the extreme minority in item 9), almost all participants had a 100% probability of choosing the correct response in both cases. For item 11 is appears that all paper-based test takers had around a 65% probability of choosing the correct response whereas this relationship did not exist for digital test takers. Item 18 intriguingly is almost perfectly dichotomous in nature within the vertical lines as those who completed the test digitally had an almost 100% probability of choosing the correct response and those who completed it on paper had around 15% probability (below the expected 20% for a 5-option item), an inverse relationship between groups can be seen at the extreme lower ability level but the population of participants in this section is marginal.

Figure 4.
Item Characteristic Curves of the PFT with 95% Confidence Intervals, Vertical lines are located at -3 and +3 theta.



As was completed above with the PSVT:R, items which visually appeared to be problematic (above 20%) in relation to the probability of choosing the correct response at -3 theta were investigated further, the values for each problematic item can be seen in Table 3 below. Some items were noted to have quite high levels of probability which calls into question their level of difficulty, and several items were identified as having quite significantly varying values between groups. The overall difference between groups in terms of guessability of all items in not significant (t(30.16) = 0.79, p = 0.435, 95% CI [-0.056, 0.128]) however items 3, 4, 5, 8, 11, 14, 15, and 18 have visibly quite significant differences between groups, and warrant further investigation to examine these.

Table 3.
Probability of choosing correct responses at -3 theta in the PFT

Item	*Percentage Guessing (rounded)*	
	Digital Version	*Paper Version*
3	*22%*	*100%*
4	*31%*	*1%*
5	*34%*	*2%*
7	*22%*	*19%*
8	*23%*	*46%*
9	*100%*	*100%*
11	*34%*	*65%*
14	*31%*	*8%*
15	*53%*	*40%*
18	*100%*	*15%*
20	*100%*	*100%*

The IRT analysis conducted for the PFT certainly raises more questions than that of the PSVT:R, however both require further investigation to support their future use.

4. DISCUSSION

4.1. PSVT:R

Through item response theory analysis, visual differences of item responses could be seen between groups but for many of the items this was not a significant difference as identified by the overlapping confidence intervals. Items 29 and 30 were found to have very little overlap, and the overlap was only observed for those at low ability levels. These two items appeared to have a significant bias towards those who completed it digitally, with approximately 100% probability of choosing the correct response in that format.

To further understand the item response theory analysis, the probability of choosing the correct response of each item was first visually inspected at -3 theta and those that were above the 20% expectation were examined further. Although when looking at the overall differences across all items between formats there was no statistically significant differences found, a number of individual items were identified as problematic as the probability of choosing the correct response dramatically changed based on format (e.g. 63% difference between formats for item 29). The cause of this difference is unknown and requires further investigation.

The internal consistency of each test format was calculated using Cronbach's alpha and was found to be reasonably similar.

4.2. PFT

Item response theory analysis was again conducted, and visual inspection was initially used to identify significant differences in test items between formats. Contrary to what was observed with the PSVT:R, a lot of the differences observed were significant, but not across all ability levels. Many of the differences observed were at the lower ability levels, suggesting those with lower abilities were impacted more by test format. Some other interesting relationships were observed such as item 3 which had a 100% probability of choosing the correct response if you completed a paper-based test, and this relationship did not then exist for digital test takers. These items were flagged for further investigation.

The probability at -3 theta was again investigated and as before several items were identified for further investigation. On item 11 paper-based test takers had a steady 65% probability of choosing the correct response no matter their ability level whereas the probability was 34% for digital test takers. Item 18 presented a more problematic situation where digital test takers had a 100% probability of choosing the correct response, whereas that of the paper-based test takers was only 15%. The reasoning behind these quite dramatic differences is unknown and further investigation is required to provide more insight.

The internal consistency of each test format was calculated using Cronbach's alpha and was found to be reasonably similar between formats.

4.3. Future Considerations

As outlined above more questions have arisen throughout this analysis around the relationships found in both the PSVT:R and PFT, highlighting the current lack of understanding around test format impacts. Stark differences in item performance and guessability were identified and further analysis is required to better understand what may cause such differences, and whether these differences are negatively impacting certain test-takers. Future research needs to examine the identified items individually to explore the differences in more detail.

Although the focus of this paper was that of the PSVT:R and PFT, many other psychometric tests are used in spatial ability research, and more broadly in educational research as a whole. The findings of this study highlight the importance of such investigations to provide insight into the validity of extensively used paper-based psychometric tests that have adopted digital formats after initial development.

This paper looked at item response theory and focussed on the probability factor of the analyses but did not focus on the parameters of discrimination, difficulty and guessing, these parameters will be discussed in a future publication. This work is important for a future applied research study to support the decision as to which medium is more appropriate.

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Design teaching in classroom practice: Phase 1 of a grounded theory study in technology education

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Abstract

Technology education is recognised as an important subject area world-wide and the international perspective on this field sees varying treatments and enactments in practice between countries. However, what has been identified as a constant component between contexts is the inclusion of design activity. Design sees a lot of ambiguity within literature describing how it is defined, the process of designing, supporting designing and how to foster designerly students. There exists a scarcity of research investigating technology teachers' perspectives on teaching to design, about design, and through design, yet as a constant element of the field this raises the question, what does design look like in practice?

A scoping review that found a distinct lack of empirical research investigating how design manifests in practice led to a narrative review that found the translation of design into teaching and learning practice to be a complex construct, these findings combined to form the need for the current research endeavour. This study aims to theorise the complexities of translating the goals of design education into teaching and learning practice. A grounded theory methodology is employed to create the necessary evidence to support future research and curriculum development. This paper presents tentative findings from Phase 1 of the project where a qualitative study was designed using semi-structured interviews to investigate design education complexity through the perspective of practicing technology teachers. In this paper, findings present how design manifests in classroom practice and how teachers are confident in supporting students designing. A discussion from these findings presented suggest that there is a gap in research about how to teach to design. These findings hold foundational value for the next phase of the research proposed to further unpack the complexities of design education in classroom practice focusing on a broader conception of breadth and functions of design teaching and learning in technology education.

Key Words: Design, Technology Education, Designing

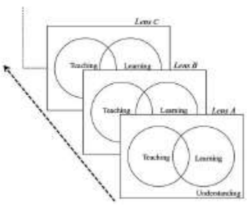
1. INTRODUCTION

Traditional areas of craft and skill development make up the roots of technology education where emergent aspects of design and technological literacy and capability lend themselves to modernising the field (Jones et al., 2013). Technology education is a recognised discipline in secondary education internationally (Buckley, 2023) with a core element of this subject area being design (Williams, 2013, 2016; Xu et al., 2020). Design education and associated research is a large and continuously growing field with seminal research still with importance and relevance today (Baynes, 2008) where design has been recognised as being essential to develop in the next generation (Baynes, 2008; Stables, 2008).

Previously, a scoping review aimed at identifying and categorising the aims of design-focused research in technology education was conducted (McDyer et al., 2022). Findings from this review highlighted the broad scope of design-focused research being conducted and identified the distinct lack of empirical research investigating how design manifests in teaching and learning practices (McDyer et al., 2022). This led to the conduction of a narrative review to problematise the uncertainty of design in technology education and led to the creation of a theoretical model. Findings indicated that translating design into classroom practice is complex and identified a lack of research investigating these complexities (McDyer et al., 2023). From this work a critical area to investigate emerged as the challenges in translating design into classroom practice which is where this current project is situated. Table 1 represents the progression into this research project, building upon the previously described work. Presented in this paper is the first phase of this grounded theory study which aims develop a theory surrounding efficacious design-focused pedagogy in technology education. A grounded theory methodology was chosen for this project to preserve the current practice without researcher bias, and preconceived concepts from literature, to gain a truthful sight into practice. Central research questions that guided this first phase were how does design manifest in classroom practice and how do teachers describe their confidence in implementing design activities. Importantly, as a grounded theory study, observations at this stage are not considered as conclusive, but are viewed as directional for subsequent phases where additional empirical and literature sourced insights will support the development and refining of the aspirational theory through a pedagogical lens.

Table 1.
Identifying the need for this project.

Scoping Review (McDyer et al., 2022)	**Results**	**Conclusion**
A categorisation of the aims of design-focused research in Technology Education	1. Design education pedagogy 2. Design education setting 3. Technological Literacy/nature of technology through design 4. Technology in design education 5. Conceptual design 6. Integrated design 7. Design thinking 8. The 'how-to' of design 9. How design is understood 10. Design cognition 11. Supporting design educators 12. Assessment in design education	There is a distinct lack of empirical research of how design manifests in teaching and learning practices.

Narrative Review (McDyer et al., 2023)	**Results**	**Conclusion**
Problematising and unpacking the uncertainty of design within technology education A theoretical model created to support investigation.  	1. There is a lack of research that shares insights into how design manifests in practice 2. Problem of design fixation and sensitiveness of design feedback 3. Design in one context may not be transferrable to another context. 4. Pedagogies in theory need intervention to be implemented in practice 5. Misuse and reliance on the internet that impedes design process 6. Varied understanding of design 7. Is design ability a construct?	Lack of research investigating the translation of design into classroom practice.

Grounded Theory Project:
Complexity of translating design into classroom practice

1st Phase:
Translating design into classroom practice from the perspective of practicing teachers.

2. CONTEXT

Each country that has formal technology education curricula has a contextual interpretation of its intended curriculum. However, Jones et al. (2013) identifies that each classroom, within each school, within each region, within that country, will inevitably have a localised interpretation of that intended curriculum. This phase of the research took place in Ireland. In Ireland, lower secondary level education is called the 'Junior Cycle' (JC) and upper secondary level is called the 'Senior Cycle' (SC). There are four technology subjects at JC level which include Applied Technology (NCCA, 2018a), Engineering (NCCA, 2018b), Graphics (NCCA, 2019) and Wood Technology (NCCA, 2018c). There are four at SC level which include, Engineering (NCCA, 1983), Construction Studies (NCCA, 1984), Design and Communication Graphics (NCCA, 2007a) and Technology (NCCA, 2007b). From subject's specifications and syllabi it is clear that the description of design is different within every technology subject in Ireland. In this study, design is treated as a singular construct composing of elements such as creativity, ideation, iteration, research and self-expression, but with an understanding that it can manifest in different forms in classroom practice. Therefore, it is important, given the pedagogical focus of this project, to maintain and critically consider representation of insights from stakeholders across multiple contexts (which in this phase of the study are different technology subjects in Ireland) in this early phase of the study. In future phases, how the contextual manifestation of design activity in classroom practice is viewed may evolve such that varied representation is not as critical.

3. METHODOLOGY

The methodology chosen for this research is classical grounded theory that is based on the foundational workings of Glaser and Strauss (1967). Later work from Glaser supporting the principle of discovering a theory, un-biased by researchers preconceived ideas and existing literature (Kenny & Fourie, 2015; O' Connor et al., 2019) further frames the study. Grounded theory utilises an iterative approach to data collection and analysis that allows the researcher to focus on developing concepts and to gather further data about these concepts by systematically interrogating data as it is gathered to refocus and direct further data collection (Charmaz & Thornberg, 2020). The reason for choosing this methodology over

Constructivist or Straussian grounded theory was the treatment of literature reviews, data analysis techniques and the philosophical paradigm that these are upheld by. This paper stemmed from a scoping review (McDyer et al., 2022) and a narrative literature review (McDyer et al., 2023) that presented gaps in the field that were deemed necessary to investigate. These reviews provided a competent rationale and justification to focus on teachers' insights in to classroom practice and avoid the pitfalls of repetition or re-inventing the wheel (Charmaz & Thornberg, 2020). This treatment is similar to that of constructivism, however these literature reviews served as a foundational introduction to the research field, to not only support this research proposal but also to gain a broad understanding of existing literature, to which is a practical reality of research (O' Connor et al., 2019). They are broad, non-focused reviews that only highlighted gaps in the field rather than to uncover concepts or theories within this study. Classical grounded theory supports that theoretical sensitivity can be more readily ensured when the researcher has not gained preconceived concepts and codes from existing literature. However, both Glaser and Charmaz, emphasise the importance of integrating the theory into the literature but at different intervals (Kenny & Fourie, 2015; O' Connor et al., 2019). As with classical grounded theory, a more focused literature review will be conducted after the core category has been identified (O' Connor et al., 2019). This will ensure that the theory presented at the end of this project will be closely integrated with the data (Glaser & Strauss, 1967), and that a theory will be discovered from the data rather than constructed or created with support from the data and pre-existing literature (Kenny & Fourie, 2015).

This paper is written at the first formal pause of the data collection whereby 5 participants were interviewed. There are no conclusive inferences being made at this stage of the project. Instead, the data analysis at this phase of the project is crucial for informing the direction of further data collection, based on the discovery of developing concepts. The first initial coding phase is presented, and findings discussed.

3.1. Data Collection

Online semi-structured interviews were employed utilising an interview protocol that conformed with the principles of classical grounded theory where researchers bias and preconceptions were limited through the delaying of the literature review, allowing the participants answers to direct the interview, all within the nature of the central research questions Open-ended questions planned in the protocol were broad to capture the natural discovery of concepts with limited bias from the researcher. The interviews ranged from 45 minutes to 1 hour and 15 minutes. Long guided interviews can force or lead the interviewee in certain directions imposing interview bias on data (O' Connor et al., 2019), so a semi-structured interview where the duration of the interview was dependent on the interviewee's self-direction and expansion on their own discussions was employed. 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, for example, *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) as opposed to convenience sampling that is described by Patton (2002, p.228) as "doing what's fast and convenient". To provide context to this technique for this particular study, the inclusion criteria for participants were as follows:

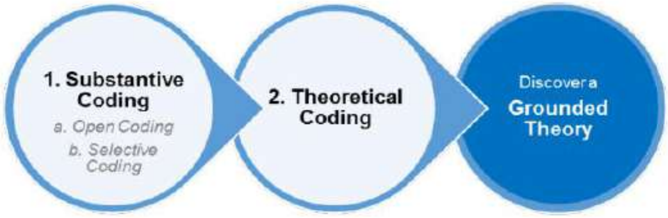
- an in-service technology education teacher at secondary level education in Ireland,
- fully qualified in the discipline of technology education,
- teaching at least 1 subject within the 4 disciplines of technology education,

The sample must include a mix of male and female participants that range from early career teachers to experienced teachers.

Participants were contacted via email by the principal investigator of the study, where information sheets, consent forms, and invitation to engage were shared. Full ethical approval was granted before this process commenced. There were 3 male and 2 female teachers that participated in this phase of the study, with an age range between 26 - 52 years old. All participants taught directly after qualifying as a teacher, and in a range of schools across the country. Early career teachers were included in the cohort to compare with experienced teachers based on their teacher education and what similarities and differences could be found.

3.3. Data analysis

Figure 2.
The coding procedure of classic grounded theory (Holton, 2010)



This phase of the project follows the coding procedure of classic grounded theory seen in figure 2 (Holton, 2010). Presented are the findings from the first stage of coding, open coding seen in Figure 2. Inductive open coding was used to gather codes, and the transcripts were analysed line-by-line. Constant comparison between codes and incidents informed codes, along with the formation of concepts and the first iteration of the theory presented in the results section. 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 concepts and to inform the subsequent interviews to follow. A sample of this reflection between interviews was the re-wording of a question from "how is design treated in practice" to "what does design look like in the classroom", which resulted in less follow-up questions and re-direction of the participants answers allowing more time to delve further into their answer.

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). Being conscious of this allowed for the interviews to be more focused as the data directed towards concepts and issues, as well as being critical in the coding that aligned with the research questions.

4. FINDINGS

The literature review phase of this project has been delayed ensuring that preconceived concepts do not result in researcher bias when conducting future data collection procedures. Therefore, these findings presented are not integrated with existing literature as this is a 'pause for analysis' in the project and so further informed data collection will take place, without bias from a literature review. Further, given that this is a qualitative study, the authors positionality will undoubtedly influence interpretations despite methods being implemented to reduce the impact of researcher biases. To that end, it should be clarified that the positionality of the authors is one of advocacy for technology teachers and students.

4.1. What does design look like in practice?

Presented are codes extracted from the data that represent what design activity looks like in the classroom, not exclusive to any subject or age range in secondary technology education. These findings represent insights to design activities that take place in all disciplines of technology education, demonstrating the similarities with design in classroom practice. All quotations in this section are direct snippets from the interview transcripts that include participants colloquialisms, and participants are anonymised.

4.1.1. Supporting design in classroom practice

When asked about what design looks like in the classroom teachers described how they support students through the design process. Teachers did not make explicit a singular process to designing when planning lessons, but shared that it incorporates (in no particular order) understanding the brief, generating ideas/concepts, comparing iterations, seeking feedback, researching, refining, modelling, making, presenting, and evaluating.

Interpreting the conversations across the teachers suggests that confidence develops over time with experience. For example, one teacher noted that "*when I started off, I suppose confidence was low in terms of design…. over the years I slowly started to piece together what the students needed to do, which is very important and like I was able to build my confidence which helped me to direct my confidence in terms of design" (Eric)*

When this is described, the teachers expressed confidence in supporting design, providing feedback, guided instruction, being the catalyst for design inspiration and teaching the procedural knowledge and skills that would open more doors to students designing. Confidence in supporting design activity seems to be developed with experience and that it is the knowing what is expected of the students and possibly having supported previous students through designing that helps to build confidence. The following findings 4.1.2. – 4.1.9. share the techniques that teachers utilise to support students designing, which brings to the fore that such practices may be supporting the students becoming better at designing, but that may not be the context in which technology teachers have been viewing these practices to date.

4.1.2. Structured Experience

Stage (developmental) appropriate projects are implemented by teachers to ensure that students have a structured experience of design that progresses in learning complexity. Consistent experience is important to fostering students' design capability. Progression in learning complexity ranges from basic/simple decision-making design tasks to difficult, informed decision-making tasks, design without fail, to design with fail, and the variance in the teacher's role in the classroom.

4.1.3. Culture

A culture of design has been described as important within the classroom when students are engaging in design tasks. Teachers describe differences between classes where there is a different culture within groups that reflect in students' effective or ineffective engagement with design tasks. A culture where students are allowed to make mistakes, try new things, seek feedback from peers and teachers and a positive fun environment support student designing.

4.1.4. Open ended and closed ended design tasks

Design tasks that are used by teachers in this cohort utilise both closed and open-ended briefs. Closed ended briefs, 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 a project

Often design activities are added at the end of a project, as an additional element. Participants describe this as a higher order activity, where students who may be finished ahead of others will add design elements to their projects. One teacher described a tractor as an engineering project and the design task at the end was to add any additional element they wanted, *"tractor [project] that they're making then they're allowed to add whatever they want after that…. link box, roll bars, exhaust" (Adam).* Described as adding their own twist or having fun. This was primarily associated with lower secondary technology education.

4.1.6. Examples and Samples

When supporting students designing, teachers would showcase examples and samples of past projects for inspiration. This also includes researching online and showing students sample products or solutions to briefs. This practice was associated by teachers as useful with students who have little experience with design activity. Students who had acquired experience with design activity were expected to research and discover inspiration themselves.

4.1.7. Supporting the refinement of designs

Teachers described a key part of their support for students undertaking design projects is to provide critical, formative, and supportive feedback to each individual student. From participant data it is interpreted that the teacher acts as the refinement mechanism in the students' design process, where the teacher will evaluate, refine, and develop a students' design to ensure not only is the design meeting the requirements and constraints but also that it is realistic to make or produce. Teachers noted that they often have to redirect or "stop" students' designs that are unrealistic to make, that go beyond that students' craft skill level, or that don't meet the constraints of the given design task. Teachers appear to be a critical part of the students' design process where their guidance and support is sought during phases of refinement and evaluation. From a perspective of developing a theory surrounding design pedagogy, this role of teachers in supporting students in the critical evaluation of and reflection on their designs relative to their capacity to make the designed artefact, the requirements of the design brief, and important potential learning is an area where teachers appear confident, and seems like a critical dimension for further exploration in terms of student learning.

4.1.8. Communicating

Sketching and modelling (both CAD and physical) are key components of each teachers design tasks in action. These methods are used to communicate the students' designs, to ensure students can think through iterations of designs and are used as comparators to other iterations in order to create a more rich, well-rounded design. Teachers describe this part of designing as a students' procedural knowledge, with one teaching noting that *"if you have a student that is good at sketching a lot of the time they're good at design as well" (Charlie).* To support designing teachers often plan for more time to develop sketching ability and skills, *"the fact that they are sketching that bit more that they're able to communicate their designs….. I hope that then long term you'll see the benefit of that" (Brid).* The final part of this quote forms an interesting thought about other benefits that the teacher is describing. Is it the benefit of advancing communication technique through a medium of sketching or is becoming a better sketcher linked to becoming a better designer? It also raises questions about the time dimension to learning to design, in that when learning outcomes associated with an improved capacity to design become apparent is an important area for further exploration.

4.1.9. Guided instruction

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. The teacher goes from the instructor and information point at lower secondary education to the facilitator at upper secondary education *"the questions are different I suppose students are coming to me rather than go to them…… they're thinking and coming up with it, it's not me going to them telling them how to do it….it's a flipped role reversal about the dynamics in the room" (Donna).*

5. CONCLUSION

A limitation of this phase of the study lies in identifying how transferrable these observations are due to being collected solely in Ireland. Future work on this project will see data gathered from other contexts to ensure an international perspective is gathered. That said, this phase of the project identified that translating design into classroom practice is complex in that there are several elements to it. The areas in which teachers expressed confidence included engaging students in design activity, in supporting students designing and in progression of skills and abilities that support design, which can be framed as teaching through design. The reform of lower secondary level technology education in Ireland means that there are now novel aspects to design related learning for teachers to engage with, and any challenging areas mentioned by the teachers may be considered as such due to a new framing of design related learning. Given that there was an expression that confidence may develop over time, then as the implementation of the reformed technology subjects continue it is likely that areas currently seen as more challenging will seem less so over the coming years.

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Developing sustainable policy and practice for design and technology educational research: engaging with stakeholders in England

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Abstract

In recent, the policy landscape for schools in England, related to research-informed teaching, has had a tendance to focus on a relatively narrow collection of research findings. These have largely centred on findings from the cognitive sciences, with government funded research favouring randomised controlled trials. This has resulted in some feelings of disaffection from teachers of design and technology, who do not see their subject reflected in the research that is promoted by senior leaders in their schools. This study focuses on policy level activism and stakeholder engagement with subject leads in school groups, such as Multi Academy Trusts (MAT), with the aim to provide a sustainable policymaking voice for the design and technology (D&T) community. The research gathers mixed methods data via an online questionnaire. The data is analysed using Self-determination Theory (SDT), identifying stakeholders' sense of autonomy, competence, and relatedness in relation to the research findings that they and their organisations value and use, making recommendations to policymakers on the access and use of subject specific research findings in primary and secondary school settings.

Key Words: design and technology education, educational research, policy, stakeholders.

1. INTRODUCTION

This study builds on the research presented by McLain et al. (2023; 2022) on the perspectives of teachers of design and technology (D&T) on educational research. These studies found that D&T educators showed strong interest in educational research, but face barriers impacting their competence, relatedness, and autonomy. They felt that they needed more support to engage with research effectively, highlighting the need for accessible, high-quality research and professional development opportunities, to become effective consumers, users, and/or producers of D&T research. In this study, the focus is on policy level activism and stakeholder engagement with subject leads in school groups, such as Multi Academy Trusts (MAT), with the aim to provide a sustainable policymaking voice for the D&T community. Whilst there is a specificity on the policy context in England, this study provides valuable insights to educators, researchers, and policymakers in other jurisdictions where design and technology education (in its broadest sense) is part of the school curriculum, both at home in the United Kingdom for D&T and in other jurisdictions where education policy promotes a narrow range of acceptable sources and types of research evidence.

2. LITERATURE REVIEW

In this section, the review of literature is presented under the headings 'policy context', exploring the national policy drivers over the past two decades in England, and 'educational research', drawing on wider literature on the value and role of research on teaching and learning in schools.

2.1. Policy Context

Recent national level educational policies in England from the Department for Education (DfE) and Office for Standards in Education (Ofsted) reveal several common themes that impact on school-level policymaking decisions.

2.1.1. Evidence-Based Practices

DfE (2017, 2013, 2011) and Ofsted (2020) have emphasised the importance of integrating evidence-based practices into education. The DfE's 2017 report on evidence-informed teaching and the 2013 report by Professor Ben Goldacre (a British physician, academic and science writer) both highlight the need for schools to engage with research to improve educational outcomes. The influence of Goldacre was, no-doubt, highly influential in the DfE's preference and bias towards randomised controlled trials (RCT), the predominant research approach in medical and pharmaceutical research, and the foundation of the Education Endowment Foundation (EEF), set up to exclusively conduct RCTs in schools. Similarly, the Ofsted article written by Professor Daniel Muijs (then deputy director of research and evaluation) underscored the necessity of basing inspection frameworks on the best available evidence.

2.1.2. Professional Development and Quality Teaching

Professional development is recurrent across the documents from DfE (2017, 2013, 2011) and Ofsted (2020). The Teachers' Standards (DfE, 2011) stresses the importance of ongoing professional growth for teachers to maintain high standards and meet diverse pupil needs. DfE (2017) also highlighted the need for a culture that values continuous learning and development, promoting high standards and evidence-based practices.

2.1.3. Disadvantaged and Vulnerable Groups

Ofsted (2020) also focussed on improving education for disadvantaged and vulnerable groups. This theme is echoed in the other documents (DfE 2017, 2013, 2011), which advocate for evidence-based practices and high standards to ensure that all pupils, regardless of their background, receive quality education.

2.2. Educational Research

This subsection provided a brief critical literature review of key themes from articles on the relevance and role of research for teachers in schools.

2.2.1. Evidence-Based Practice

A recurring theme across the literature is the emphasis on the importance of evidence-based practices. Perry (2022) and Perry et al. (2021) highlight the potential of cognitive science to enhance classroom practices, yet they caution that much remains unknown about its practical application, despite the recent DfE bias towards findings from the cognitive sciences and the use of RCTs. Voices from the last century, Stenhouse (1975) and Rudduck & Hopkins (1985) advocated for research as a foundation for teaching, emphasising the need for systematic inquiry to inform educational practices, an aim that holds true to the present day.

2.2.2. Professional Development

Stremmel (2007) underscored the value of teacher research in fostering both professional and personal growth, focusing on teachers of engineering and technology in the USA. Skogh and de Vries (2013) illustrated how engaging teachers in research can enhance their understanding and teaching of technology, based on experiences in Sweden. These present-day perspectives align with Stenhouse's (1975) call for teachers to be active participants in curriculum development and research.

2.2.3. Challenges

Several papers also discuss the challenges of translating research into practice. Perry (2022) points out the limitations of exclusively applying cognitive science in real classroom settings. Perry et al. (2021) also noted the limited evidence on how cognitive science strategies can be effectively implemented across different subjects and age groups, highlighting the risk of narrowing or nationally mandating sources of evidence to inform classroom practice. These challenges highlight the need for more practical research and support for teachers in applying these findings.

2.2.4. Teachers as Researchers

Strimel (2007) and Skogh and de Vries (2013) both emphasise the benefits of teachers conducting their own research to improve their practice and contribute to the broader educational community, echoing the central of Stenhouse (1975) who advocated for a research-based approach to curriculum development back in the 1970s.

2.3. Summary

By identifying these common themes, it becomes clear that fostering a culture of evidence-based practices, continuous professional development, and high standards is at the heart of the expressed aims for the DfE and Ofsted, as the national level policymakers, and others. However, the implementation approaches between policymakers and D&T scholars have marked differences in how to achieve this. The elements collectively contribute to school-level decision making, with the real influence being from DfE and Ofsted who have the power to enforce policy through direct and indirect means. Whilst the aims of both ‘sides’ of the debate are laudable the reliance on high profile individuals to set the tone for educational policy on research-informed and evidence-based teaching is open to bias and over emphasis on particular ways of knowing and understanding the educational landscape.

3. RESEARCH DESIGN

This study adopts a mixed methods approach, grounded in the pragmatic paradigm (Biesta, 2022; Guba, 1990; Dewey, 1916), which emphasizes practical solutions to research problems (Creswell, 2014). The axiological stance underscores the importance of providing high-quality, subject-specific research to educators in design and technology. The sampling approach was purposive, targeting educators with subject leadership roles across schools in England, such as subject leads in Multi Academy Trusts (MATs), ensuring that participants had relevant expertise and experience, and were in a position to influence subject level policy across schools. The research was conducted under the ethical approval of the author’s university research ethics committee (UREC), following the principles laid down by the British Educational Research Association (BERA, 2018).

The quantitative component involved an online questionnaire survey, designed to gather broad and potentially generalisable data on educators' perceptions and practices. Likert scale questions were used, and descriptive analysis was undertaken, with Pearson Correlation Coefficients generated to identify potential relationships between particular questions. The qualitative component included open-ended questions within the survey, allowing for in-depth exploration of participants' experiences and insights. This combination of methods enables a comprehensive understanding of the research problem, leveraging the strengths of both quantitative and qualitative data (Creswell & Creswell, 2018; Creswell & Plano Clark, 2017).

Whilst the mixed methods research (MMR) design is commonly used in educational research and is generally accepted as offering robust insights, it also presents challenges. The integration of quantitative and qualitative data requires careful planning and execution to ensure coherence and validity. Additionally, the purposive sampling, while ensuring relevance, and small sample size limits the generalisability of the findings. Future research could benefit from a larger, more diverse sample to enhance the study's external validity.

2.4. Theoretical Framework

This study employs Self-Determination Theory (SDT) as the theoretical framework to analyse the motivations and experiences of the participants (Ryan & Deci, 2017; CSDT, n.d.). SDT posits that human motivation is driven by the fulfilment of three basic psychological needs: competence, autonomy, and relatedness (Ryan & Deci, 2000). Competence refers to the need to feel effective and capable in one's activities. In the context of this study, it examines how educators perceive their ability to influence the value and availability of high-quality design and technology research. Autonomy involves the individual's need to feel in control of their actions and decisions. This study explores the extent to which participants feel able to influence subject-specific policy in their organisations. Relatedness is the need to feel connected to people, policies and practices. The study investigates how connected the participants feel to decision making that affects how D&T is taught and understood in their organisations. Utilising SDT, this study aims to provide a nuanced understanding of the factors that motivate leaders in D&T to identify and promote the use of high-quality research in the teaching practices of the organisations that they have influence over. This framework aligns with the pragmatic paradigm of the study, emphasising practical solutions to enhance educational outcomes.

4. FINDINGS

Of the ten (10) participants who responded to the invitation to participate in the survey, eight (8) were D&T leads for MATs in England, one (1) was a leader in a national organisation supporting he subject, and one (1) in a school with a leadership role for a facility accessed by local schools. Whilst the sample size of MAT D&T leads is small, this is a relatively new and emerging role and not all trusts have appointed or publish the names of foundation subject leaders. Most of the participants also have an active profile in the national D&T community on social media and other platforms. Whilst this opens the study to potential self-selection or volunteer bias, a mitigating factor is the aim for the findings to fuel subject level activism, provide evidence to challenge hegemonies, and increase agency for others in these roles. The questionnaire asked participants to respond to twenty (20) quantitative Likert scale statements in the first section of the survey, and four (4) qualitative questions to explore views and experiences in the second, the responses from which are presented in the subsections below.

Table 1.
Likert Scale Statements (5-point, strongly agree to strongly disagree)

Q1. Educational research is valued by my organisation.
Q2. Research is used in decision making by my organisation.
Q3. Research is promoted by my organisation.
Q4. My organisations promotes a wide range of different types and sources of research.
Q5. My organisations actively encourages teachers to read and use research in their practice.
Q6. My organisation has a policy relating to the use of research.
Q7. In general, policies have a positive impact on classroom practice in my organisation.
Q8. I am in a position of influence when it comes to how design and technology is viewed and experienced in my organisation.
Q9. I have used research to inform how design and technology is understood and experienced in my organisation.
Q10. National education policy for schools has positively influenced the use of research in my organisation.
Q11. I can find good quality, design and technology relevant, research easily on the internet.
Q12. My organisation knows what is reliable and trustworthy research.
Q13. I would support my organisation having a policy on the use of subject specific research in the design and technology classroom.
Q14. I understand what the peer-review process involves in the publishing of research.
Q15. I know where to find peer-reviewed research on design and technology education.
Q16. Time is a barrier for my colleagues to be able to access and use design and technology research.
Q17. Access to reliable sources is a barrier for my colleagues to be able to access and use design and technology research.
Q18. There is a desire from my colleagues to access and use design and technology research findings in their practice.
Q19. Teachers in my organisation are encouraged to engage with practitioner research (e.g., Action Research, Lesson Study, etc.)
Q20. I have observed examples of where engaging with design and technology research has improved learning in my organisation.

4.1. Quantitative Data

Table 1 presents the twenty (20) statements that participants were asked to respond to with Strongly Agree, Somewhat Agree, Neither Agree nor Disagree, Somewhat Disagree, or Strongly Disagree. The statements related to the role that research evidence plays in the participants' organisations, their own knowledge of D&T research, and their experiences of how research is used in their own practice and that of their colleagues.

Figure 1 (below) graphically represents the response rates for each statement. All participants either strongly (70%) or somewhat (30%) agreed that educational research is valued in their organisation (Q1). In terms of the use of research to inform decision making (Q2), the response rates remained positive albeit inverted with 10% strongly and 90% somewhat agreeing. The responses become a little more mixed in response to whether research is promoted by their organisation (Q3), with 30% strongly, 60% somewhat, and 10% neither agreeing nor disagreeing.

Figure 1.
Response Rates to Likert Statements by Percentage (%)

Table 2.
Pearson Correlation Coefficients for Likert Scale Statements (r > 0.7 in green)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
Q1	1																			
Q2	0.2182	1																		
Q3	0.5819	0.4444	1																	
Q4	0.6245	0.3887	0.5653	1																
Q5	0.4166	0.3939	0.3939	0.7420	1															
Q6	0.1455	0.1111	0.3889	0.6713	0.5152	1														
Q7	-0.3067	0.1562	0.1562	0.2814	0.4401	0.3644	1													
Q8	0.2182	0.1667	0.1667	0.7420	0.5455	0.6667	0.5466	1												
Q9	-0.3553	-0.3512	-0.1916	-0.0914	0.3744	0.0319	0.6432	0.0479	1											
Q10	-0.0546	0.1667	0.5833	0.2120	0.2045	0.2500	0.7418	0.3750	0.2873	1										
Q11	-0.2440	0.3727	0.3727	-0.1185	-0.3049	-0.1863	0.3492	0.0000	-0.2142	0.6988	1									
Q12	0.2667	0.1111	0.4815	0.4358	0.5152	0.2593	0.7115	0.3889	0.4576	0.6667	0.2485	1								
Q13	-0.2182	-0.1667	-0.1667	0.0530	0.3636	0.5833	0.2343	0.2500	0.4310	-0.0625	-0.5590	-0.1111	1							
Q14	-0.1502	0.0765	-0.3059	-0.0243	0.1460	0.3059	-0.1075	-0.1147	0.1318	-0.5449	-0.6412	-0.3314	0.6882	1						
Q15	-0.0935	0.5238	0.2857	-0.1666	-0.2987	-0.2857	-0.0669	-0.4286	-0.2600	0.1071	0.4792	-0.2063	-0.2857	0.1311	1					
Q16	0.3563	-0.4082	0.2722	0.5626	0.1485	0.4082	0.2550	0.6124	0.0782	0.3572	0.0000	0.4082	-0.1021	-0.4215	-0.4082	1				
Q17	-0.5819	-0.4444	-0.1667	-0.2120	-0.0909	0.1667	0.1041	-0.1667	0.3512	0.0417	0.0000	-0.1111	0.1667	-0.0765	-0.2857	0.0680	1			
Q18	-0.0546	0.1667	0.5833	0.4770	0.4318	0.6667	0.7418	0.3750	0.4071	0.6875	0.2795	0.6667	0.2500	0.0287	0.1071	0.3572	0.2500	1		
Q19	0.7167	0.4772	0.7579	0.8302	0.7579	0.5053	0.3814	0.5474	0.0565	0.4421	0.0000	0.6456	0.0842	-0.0386	0.0361	0.3782	-0.4772	0.5474	1	
Q20	0.1954	0.2322	-0.0995	0.5590	0.8051	0.2653	0.2953	0.3980	0.4479	-0.2239	-0.5562	0.2101	0.3483	0.4109	-0.2417	0.0406	-0.0663	0.1493	0.4274	1

Table 2 (above) shows the Pearson Correlation Coefficients between the responses to each of the statements. These correlations help identify which questions are related and how strongly they influence each other. Focusing on the strong positive relationships (r > 0.7), the key relationships are detailed in Table 3 (below), which identifies the ten (10) strong correlations. Correlations 1 and 2 show a relationship between an organisation's promotion of a wide range of different types and sources of research (Q4) –in contrast to the national bias towards findings from the cognitive sciences and RCT studies– and both (a) the encouragement for teachers to read and use research in their practice (#1) and (b) the participant being in a position of influence regarding organisational policy (#2). This indicates that the organisations represented by the participants are willing and able to look beyond the confines of national policy directives and foster a more inclusive and nuanced approach to local policy and practice, valuing different forms of knowledge across subjects.

Table 3.
Relationships Between Strongly Correlating Statements

No.	Relationship (r)	Interpretation
1	Q4 and Q5 (0.7420)	The is a relationship between whether an organisation promotes a wide range of different types and sources of research **and** whether they actively encourage teachers to read and use research in their practice.
2	Q4 and Q8 (0.7420)	The is a relationship between whether an organisation promotes a wide range of different types and sources of research **and** the leader being in a position of influence when it comes to how D&T is viewed and experienced.
3	Q7 and Q10 (0.7418)	The is a relationship between whether policies have a positive impact on classroom practice in an organisation **and** national education policy positively influencing the use of research.
4	Q7 and Q12 (0.7115)	The is a relationship between whether policies have a positive impact on classroom practice in an organisation **and** they know what research is reliable and trustworthy.
5	Q7 and Q18 (0.7418)	The is a relationship between whether policies have a positive impact on classroom practice in an organisation **and** a desire from colleagues to access and use D&T research in their practice.
6	Q1 and Q19 (0.7167)	The is a relationship between whether educational research is valued by an organisation **and** teachers are encouraged to engage with practitioner research.
7	Q3 and Q19 (0.7579)	The is a relationship between whether research is promoted by an organisation **and** teachers are encouraged to engage with practitioner research.
8	Q4 and Q19 (0.8302)	The is a relationship between whether an organisation promotes a wide range of different types and sources of research **and** teachers are encouraged to engage with practitioner research.
9	Q5 and Q19 (0.7579)	The is a relationship between whether an organisation actively encourages teachers to read and use research in their practice **and** teachers are encouraged to engage with practitioner research.
10	Q5 and Q20 (0.8051)	The is a relationship between whether an organisation actively encourages teachers to read and use research in their practice **and** the participant having observed examples of where engaging with D&T research has improved learning.

Similarly, there was a strong relationship between the statement relating to the positive impact of policy on practice (Q7) and the beliefs that (a) national policy positively influences the use of research (#3), (b) they know what reliable and trustworthy research is (#4), and (c) there is a desire from colleagues to access and use D&T research (#5). Together, these relationships indicate that actively embracing national policy directives does not necessarily mean that an organisation accepts every assumption or value promoted, but provides a motivation and direction upon which to build organisational policies and practices. So, whilst the national policy can be viewed as a straitjacket where it leads to a narrow selection of 'acceptable' research findings, as found by McLain et al. (2023; 2022), a strong a principled leadership on how it is interpreted and operationalised can lead to very different and more inclusive outcomes.

A third theme emerging from the strongly correlated statements relates to whether teachers are encouraged to engage with practitioner inquiry, as producers of research (Q19). There was a strong relationship between this and four (4) other statements: (a) educational research being valued by the organisation (#6); (b) educational research being promoted by the organisation (#7); (c) promotional of a wide range of types and sources of research (#8); and (d) teachers in the organisation being actively encouraged to read and use research (#9). McLain et al. (2023) identified three levels of teacher engagement with research: consumers, users and producers. Whilst it should not be considered as a progression path necessary or desirable for every teacher to aspire to and attain the third level and become active teacher-researchers, it does require increasing knowledge, commitment and support to engage at this level. Therefore, a commitment from an organisation, be it a single school or school group (such as a MAT), to support and encourage practitioner inquiry could be viewed as a prerequisite for effective and sustainable policy on research in schools. And this includes recognising the nuances of subjects and the different knowledges associated with them, and a more pluralistic approach to how knowledge is gained and validated.

The fourth strong relationship identified was between the organisation actively encouraging teachers to read and use educational research and the participants observing examples of the use of research findings improving learning (#10). This suggests that policy has a direct relationship to practice, although this correlation, in itself, does not prove a causal relationship in a particular direction – i.e. policy changes practice, such as the policy creating a climate where practice is positively affected and changed.

In summary, whilst the numbers of participants are small, making the findings not statistically significant, there are some interesting and useful findings that might inform policy level activism and inform more sustainable approaches to policymaking in school settings. The next subsection explores some of the qualitative responses from participants.

4.2. Qualitative Data

A thematic analysis of the qualitative comments provided by the participants is outlined below.

Q6 Please provide any further comments to elaborate on or illustrate your responses...
Participant 1 highlighted the value of peer-to-peer lesson observations, indicating trust from senior leadership and encouragement to try new teaching methods. Regarding the use of research, Participant 2 emphasised the importance of using peer-reviewed research over educational books by non-researchers to ensure robust research processes, whereas Participant 10 noted that few D&T teachers actively use research to inform practice, with many being dismissive of research. Participant 6 stated that most learning about updating the D&T curriculum comes from face-to-face collaborations or workshops, and Participant 8 pointed out the limited availability of research in design and technology compared to other subjects, suggesting the need for a database of recognised research. This suggests that readily available information and knowledge is given preference by busy teachers. Participant 9 described how they oversee D&T across several schools, commenting on variability in research engagement and the support for academic research. These themes reflect the diverse perspectives on the use of research, professional trust, and collaboration within the educational context.

Q7 Where do you access design and technology research?
The response to this question elicited responses under the themes of:

- Online Platform: participants frequently mentioned accessing research through online journals, Google Scholar, and websites.
- Books and Publications: several participants noted using books, including those from reputable and specialist publishers.
- Professional Networks: forums, social media (e.g. Twitter, Facebook), and network meetings were highlighted as valuable sources.

Participant 4 emphasised the value of discussions and podcasts for understanding research, suggesting that these formats help capture the essence of the research better than written work. The Design and Technology Association (D&TA) was mentioned by multiple participants as a key resource, and Participant 2 specifically referred to Design and Technology Education: An International Journal, which is the association's peer-reviewed journal, as a primary source of research. Participant 8 also highlighted the use of research during a postgraduate degree and the importance of academic grounding in research. These themes reflect the diverse methods and resources that the participants use to access and engage with D&T research.

Q8 What, if anything, would have a positive impact on how design and technology research is actively engaged with in your organisation?
Participant 1 emphasised the value of the subject due to good student outcomes and improved experiences through STEAM (science, technology, engineering, art, and mathematics) activities. Participant 2 highlighted the importance of active communication with their Trust, regarding the latest research to influence subject performance. Participant 4 suggested paying teachers to engage in research and offering grants to provide more opportunities for D&T teachers to contribute valuable work. Participants 6 and 10 mentioned the need for national data and evidence repository to support outcomes, whereas Participant 8 focused on demonstrating positive impacts on learning outcomes and exploring research on subject leadership and cross-curricular links, and Participant 9 stressed the need for time for staff to engage with research. These responses reflect the diverse perspectives on how to enhance engagement with D&T research within educational organisations, with no clear themes emerging – except for the need for a national repository of evidence for D&T, linking with a response to Q6 above.

Q9 What, if any, design and technology research are you interested in in your organisation?
As with responses to Q8, above, there were no clear and shared themes from the participants. However, seven (7) participants offered suggestions for research priorities:

- Participant 1: industry-related research and preparing students for external examinations and apprenticeships, highlighting a strong track record for learner destinations;
- Participant 2: formative assessment within design and the impact of D&T subjects on student attainment;
- Participant 3: exploring the pros and cons of teaching using 'carousel' timetabling (where lower secondary school classes rotated between teachers, classrooms, and units over the academic year, so each group experiences the units in a different sequence), methods for assessing process verses outcome, and how different lower secondary school models impact upper secondary school outcomes;
- Participant 4: exploring the use of practical work to embed knowledge, teaching technical vocabulary, and how learners learn in D&T;
- Participant 6: the balance between skills and knowledge in D&T education.
- Participant 8: the positive impact on learning outcomes, cross-curricular work (e.g., integrating mathematics or sustainability), and what constitutes a good curriculum in lower and upper secondary school;
- Participant 10: defining a modern D&T curriculum and accurately assessing creativity and problem-solving without compromising their essence;

Whilst each of the suggestions offer a unique insight into the priorities of the individual participant and organisations, there is a common thread related to the practicalities of curriculum intentions, implementation, and impact, which reflects the criteria for the current Ofsted (*cf* 2023, 2018) inspection framework.

4.3. Summary

The quantitative and qualitative data from the small sample of D&T leaders in this study provides rich insights into the policy context for the use of subject specific research.

5. DISCUSSION

5.1. A Self-Determination Theory Perspective

SDT focuses on the three basic psychological needs for autonomy, competence, and relatedness. Using SDT as a framework to briefly analyse the findings from this study, the participants' responses suggest the following insights.

5.1.1. Autonomy

Participant 1 highlighted the value of peer-to-peer lesson observations and the trust from senior leadership to experiment with new teaching methods. This supports the need for autonomy by allowing teachers to make independent decisions about their teaching practices. The findings also support the notion that that the organisations represented promote a wide range of research types and sources, encouraging teachers to read and use research. This also fosters a sense of autonomy as teachers can choose the research that best fits their needs and interests.

5.1.2. Competence

Participant 2 emphasised the importance of using peer-reviewed research over non-research-informed educational books helps teachers feel more competent in their practice by ensuring they are using reliable and robust information and knowledge. The encouragement for teachers to engage with practitioner inquiry and the provision of resources such as workshops and collaborations enhance teachers' skills and knowledge, also increases their sense of competence.

5.1.3. Relatedness

The findings also highlight the importance of face-to-face collaborations, workshops, and active communication with school group leaders and professional networks. This has been somewhat lacking in England in recent years, but there is evidence of increased interest through events such as PATT40 Liverpool 2023 conference and The Big D&T Meet 2024, in Norwich. These interactions help build a sense of community and relatedness among teachers.

Variability in research engagement across the schools represented by the participants and the support for academic research indicate efforts to create a supportive environment where teachers feel connected and valued. By addressing these three psychological needs, the findings suggest that organisations in England, such as MATs, can create a more motivating and supportive environment for teachers, ultimately leading to better educational outcomes for learners. Whilst the study focus on D&T in groups of schools in England, anecdotal evidence suggests that the findings are readily transferable to other school subjects and diverse national contexts.

5.2. Recommendations

Whilst this study focuses on the policy context for D&T in England, the learning and recommendations may serve as a salutary warning to technology education communities around the world of the potentially fragile nature of the subjects in the eyes of policymakers and school leaders. It highlights the need for teachers and subject leaders to be aware of the research in their field and have access to knowledge and understanding to adapt to and challenge generic or narrowly informed policy decisions, as appropriate.

The key recommendations are for D&T subject leaders to leverage their influence within their organisations to advocate for subject specific research to be valued and promoted. It also indicates some of the key indicators for successful implementation, including the active encouragement and support for teachers to engage with research as consumers, users, and producers. Subject leaders play a vital role in the local and national vibrancy of professional communities and networks, and access to quality research packaged in an accessible format for busy teachers is most likely to increase agency and fuel activisms, to foster fair and inclusive educational policy at the national and organisational levels. Thus, providing thoughtful and bespoke policies at the organisational level that translate national directives into sustainable and impactful practices, which are informed by and contribute to research-informed teaching.

Through the unintended consequences of top-down policy decisions, general education subjects that do not align with the current national priorities or proclivities can easily become marginalised, as has been the case for D&T in England. Whilst not quite a playbook for lobbying and activism, it seeks to provide a new perspective for teachers, scholars and policymakers in related fields around the world.

5.3. Acknowledgements

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Adoption of Generative Artificial Intelligence in K12 Design and Technology Education

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Abstract

Technological artefacts and tools play a crucial role in design and technology (D&T) education as they support the mediation between individuals and their environment. With the advent of generative artificial intelligence (Gen-AI), popularised by large language models and tools, D&T practices are being challenged as the technology is being integrated into the educational landscape. Although AI is attracting growing attention because of the potentialities it offers, it is not yet clear about the reasons underlying an adoption and/or rejection when addressing educational, but also technical and social challenges in classrooms. This paper investigates these reasons adopting a mixed research methodology which involves a survey addressed to D&T educators to collect their views and determine factors that influence AI adoption, and a case study that discusses ten capabilities from three well-known Gen-AI platforms (Midjourney, Padlet, and Newarc.ai) with respect to D&T teaching and learning. Results from the survey showed that participants recognised the value, accuracy and benefit of AI in D&T in a very high level of acceptance, whereas trust in transparency, explainability, privacy and data security depicted a different viewpoint, indicating potential uncertainties around AI. Additionally, a couple of strong pairwise correlations were found between drivers. These results are particularly important as they provide directions and insights into the development and validation of a framework towards AI adoption with respect to D&T but also practical implications for research and education when developing effective, efficient and personalised AI-supported instructions.

Key Words: Artificial intelligence, AI Adoption framework, Design and technology education, Generative AI, Generative design.

1. INTRODUCTION

The integration of artificial intelligence (AI) into education has attracted considerable attention in the recent decade and shown a potential transformative impact on all levels of educational settings. This embracement encompasses a broad spectrum of applications ranging from administrative, human resource tasks to intelligent tutors, chatbots and personalised learning (e.g. Zhang and Aslan, 2021). Within AI, generative AI (Gen-AI) has emerged to be a driving force. Powered by popular models such as generative pretrained transformers (GPT), bidirectional encoder representations from transformers (BERT), Gemini, LLaMA, etc. this technology has enabled capabilities in the automation and/or semi-automation of several ordinary human tasks in the academic workplace. However, this implementation is not without concerns namely technical, ethical, social, etc. (e.g. Zhang & Aslan, 2021; Luan et al., 2020), a 'dark side' (Wach et al. 2023) that need to be addressed for the benefits of education.

Of importance is understanding the adoption and/or rejection of AI in design and technology (D&T) education. While there are a bunch of research in higher education, however, few is known when it comes to the adoption by K12 D&T educators. This paper explores this issue and examines factors that influence AI adoption while identifying the benefits, challenges and future directions of this rapidly developing AI technology. By collecting teachers' views and discussing a case study on AI in D&T education, the paper aims to give a comprehensive overview of how the technology shapes the D&T education landscape and what this would mean for educators, learners and policy makers. The paper provides theoretical elements towards a framework for the adoption of AI as well as recommendations on its use in K12 D&T education.

Table 1.
Examples of existing frameworks on the adoption of AI technology in academia and education

Contexts	Examples of frameworks-models used or developed	References
Educational organizations and academia (university, higher education, libraries, human resource)	Unified Theory of Acceptance and Use of Technology (UTAUT); - Technology Organization Environment (TOE) framework; - Framework assessing when and how AI could enhance academic pursuits; - UTAUT; - TPACK.	Ahmad et al. 2023; Sharma et al., 2024; Andrews, Ward, and Yoon, 2021; Yawson, 2024; Jo and Bang, 2023; Strzelecki and ElArabawy, 2024; Jain and Raghuram, 2024; Tanantong and Wongras, 2024.
Education and teacher education	"Five S" prompting framework for assessment; - TPACK and UTAUT frameworks – UTAUT; - Davis's TAM and Biesta's Three functions of education	Tassoti, 2024; O'Dea and O'Dea, 2023; Xiaohong et al. 2024; Butler and Starkey, 2024
User experience and perception	UTAUT; - Technological Acceptance Model (TAM) and the Moral Foundation Theory with a Three-pronged approach;	Lin, Ho, and Yang, 2022; Ho, Mantello, and Ho, 2023

1.1. Background: frameworks and adoption factors

A rapid review in the Web of Science database shows that the last decade has witnessed a growing interest in AI adoption in education globally. This tendency is also confirmed by a recent review of Bahroun et al. (2023) who identified Gen-AI as having an exponential growth in research, and ChatGPT as a dominant Gen-AI tool. Several frameworks and models have been developed and used to frame the adoption of AI in academia (Table 1). For instance, Jo and Bang (2023) investigated factors in the adoption of ChatGPT with the 'technology – organization - environment' (TOE) framework using the concept of knowledge application. They found that quality of network, accessibility, and system responsiveness contributed to satisfaction. Ho, Mantello, and Ho (2023) combined the 'technology acceptance model' (TAM) and the 'moral foundation theory' (MFT) with an analytical framework, i.e. a 'three-pronged' approach to study determinants of emotional AI's acceptance. Andrews, Ward, and Yoon (2021) utilised the unified theory of acceptance and use of technology (UTAUT) as a framework to predict librarians' intentions to adopt AI and related technologies. While they concluded that the UTAUT framework can be a viable framework to study intentions in adoption, they found that performance expectancy and attitude toward AI had strong effects on intentions, whereas social influence and expected effort did not. Elkefi, Tounsi, and Kefi (2024) also used this model to investigate engineering students' use of ChatGPT. Most students used the chatbot with strong UTAUT predictors being highlighted. Similar to this, Cortez et al. (2024) utilised the extended UTAUT, that is UTAUT2 from (Venkatesh et al. 2003), and a self-determination theory to point out variables like promoting conditions, habits and performance expectations had a direct impact on behavioural intention and an indirect effect on educational use. As for Mazarakis et al. (2023) a theory of human-centred interdisciplinary AI, that is for instance the synergistic human-AI symbiosis theory (SHAST) can be relevant to address interactions. Richardson et al. (2022) developed a framework based on patients' experiences, beliefs and attitudes towards AI in healthcare. Their study concluded that patients' attitudes and beliefs towards healthcare AI were the first decisive steps to effective patient participation and education.

While there is evidence of research developments in education globally, however, few of these applications are specific to K12 D&T teaching and learning. What can be learned from literature is that critical factors are driven by trust, safety and ethical issues in most cases. According to Yawson (2024), two principles appear to be crucial in adopting technologies such as AI: the 'substantial equivalence principle' which suggests that assessing new technologies are based on how functionally comparable they are to existing accepted practices, and the 'precautionary principle' that is the technology undergoes rigorous risks' assessment before its widespread adoption. This is positioned as two ends of a spectrum of viewpoints on integrating emerging Gen-AI into academia. Sharma et al.'s (2024) study showed significant relationships between factors including self-efficacy of AI, behavioural intention, AI adoption in higher education, and perceptions of risk, usefulness, effectiveness and organizational support. However, perceived usefulness was not identified as a significant factor in influencing the intention to adopt AI in higher education in Jain and Raghuram's (2024) study. Notably, they viewed key drivers such as perceived ease of use, TPACK, and trust. Li et al. (2024) reviewed findings on interpersonal trust, human automation and human AI from a three-dimensional perspective based on trustee, trustor and their interactive contexts. Their framework summarises factors related to trust formation and dynamics among different trust types. They argued that these factors clearly define the baseline for the development of reliable AI and provide guidance for its development, especially for user education and training. Similar to these is the study of Ayanwale and Ndlovu (2024) who evidenced that students who recognise the advantages of chatbots have shown a strong intention to use it for educational purposes. They found relationships between benefits, compatibility, trialability, trust, perceived usefulness, perceived ease of use, and behavioural intention. For Elkefi, Tounsi, and Kefi (2024) who investigated engineering students' adoption of ChatGPT, determinants like peer support, high frequency use, perceived benefits positively influence intention of using ChatGPT, whereas concerns about laziness, accuracy, privacy are negatively related to the intention to use. As research increases, other drivers (e.g. emotional, empathy, cultural) can be central in uncovering human-AI interactions in D&T.

1.2. Towards a framework for the adoption of AI in K12 design and technology education

Let us now recontextualised the use of AI in D&T education within the technology education literature. Over its relatively brief history, technology education has had foundational connections with technological artefacts, tools, and objects. This has been subject to intense philosophical, epistemological, sociocultural, and educational debates among researchers. From a philosophical point of view, researchers have identified four types of technology means: 'technology as artefacts', 'as knowledge', 'as activities', and 'as a characteristic of humanity' (Mitcham 1994). Jones et al. (2013) discussed that these categories appear to be relevant to D&T education. For instance, artefacts have both physical and functional nature. They can be multifaceted (Verkerk et al. 2015), e.g. physical object with an interface such as robots or 3D printers. As a computational model aiming to simulate human reasoning, AI is an intelligent modelling tool embedded into virtual and physical artefacts (e.g. computers, tablets). This refers to the artefactual account of models which Nia and de Vries (2016) describe as 'techno-scientific artefacts' of dual nature: intrinsic and intentional.

'Technology as knowledge' helps clarify the characteristics of technological knowledge (e.g., normativity, propositionality, taciteness, ill-structuredness). 'As activity', technology fosters the design learning experience through the design process whereas 'technology as characteristic of humanity', which Jones et al. (2013) consider as the most grounded one, focuses on improving socially learners' experience of the world. While all these four means are integrated and taught together (Ibid.), teachers can for instance propose the design of artefacts inspired by AI - used as a tool, to explore variety of innovative artefacts they want students to design; It is also possible to develop activities that reflect on the non-linear design process (technology as activity), and confront student prior knowledge with technological knowledge conveyed by the AI-inspired artefact (technology as knowledge); Finally, with respect to technology as characteristic of humanity, educators can let students think about the values and concerns (e.g. ethics, originality, empathy bias, intellectual property, etc.) associated with the AI-inspired artefact.

Technology education puts a particular emphasis on the human activity as mediated by artefacts and tools. With this, D&T activities are embedded in the epistemology of technology, i.e. they are built and developed from a complex (functional and systemic) way of thinking. This allows to distinguish the teaching of technology (non-linear thinking aimed at concretizing objects or systems) from that of other scientific disciplines (de Vries, 2016). From an instructional perspective, D&T education adopts a pragmatical view in building with the learners the know-how, know-what and know-that, etc. with respect to any (Gen-AI) tools.

Broadly situated, the general use of AI in D&T can be shared across many application areas, with a critical determinant factor that is trust. This (potentially) explains why most research proliferate in higher education when K12 education remains more cautious. In this regard, Ofosu-Ampong et al. (2023) trustworthy issues are particularly adaptable to question D&T educators' scepticism. This is also discussed in Li et al. (2024) who adopted a three-dimension framework (i.e. the trustor, trustee, and their interactive context) to identify key interpersonal, human-AI trust and human-automation drivers. However, there is a lack of considerations for specific elements related to teaching and learning in D&T education. Although samples of generic D&T tasks like planning lessons, effective management of administrative tasks (e.g. Ahmad et al. 2022), seeking feedback and grading (Rutner & Scott, 2022), developing teaching and learning resources (Song et al. 2024; Druga, Otero & Ko, 2022; Ng et al. 2023), using AI as a pedagogical tool (Celik, 2023), to enhance traditional pedagogical approaches (Darda, Gupta & Yadav, 2024), or create novel ones can be found in literature, yet specific D&T tasks that support most D&T instructions are to be explored further. To support the effective use of the technology, educators can also teach about how to use AI in the D&T classroom (Ho et al., 2019; Ng et al., 2023). Teaching and learning D&T provides a unique opportunity to investigate the nature of technological artefacts and tools as cultural mediators (e.g., Impedovo et al., 2017) as discussed above. It is believed that when included in a well-informed process of thinking relevant to D&T, AI can support teachers in developing relevant technological and pedagogical contents and enhance the teaching-learning process. For instance, AI can support multimodal ideation and the making process with cognitively deficient learners while discussing the challenges of tools and their choice. Notably, Vartiainen and Tedre (2023) found that AI can inspire educators to consider both the unique nature of crafts and the tensions of introducing it into design and crafts practices.

1.3. Research Objective

This paper aims to provide an overview of the adoption of AI in K12 design and technology education and brings pieces together for the elaboration of a framework on the adoption of AI. It builds on educators' views on their use and the applications of AI in their daily instructional practices, as well as factors that contribute to explaining AI adoption in the educational workplace, especially for teaching and learning purposes. With respect to that, the study also presents a case study that investigates three advanced Gen-AI tools and discuss their opportunities and challenges, as well as recommendations when developing AI-supported instructions.

2. METHODOLOGY

Data were collected following a mixed research method combining a survey distributed to D&T educators in the UK (via the D&T Association and CLEAPSS mailing lists and posted on LinkedIn) to collect their views on the use of Gen-AI and a case study describing some capabilities of Gen-AI in D&T classrooms. 19 teachers of D&T completed the survey (see survey findings below). All computations were performed on Microsoft Excel to obtain the visualisations and descriptive statistics. The next section presents a multi-platform case study of the potential for the use of Gen-AI in D&T.

3. EXAMPLES OF GEN-AI USE IN D&T

The examples below explore and exemplify the application of three advanced AI tools in the context of teaching design and technology: Midjourney, Padlet, and Newarc.ai. These tools leverage artificial intelligence to create and manipulate visual content, enhancing the teaching and learning experience. By examining their use in classroom settings, this study highlights their potential to improve resource creation, student engagement, and the iterative design process.

3.1. Midjourney

Midjourney is an AI-powered tool that generates images from text descriptions. It assists artists and designers in quickly creating detailed and creative visuals based on their input. The images produced can range from realistic to highly stylised, depending on the given prompts. Among various text-to-image AI generators, Midjourney is renowned for its high-quality outputs, comparable to other leading tools such as DALL-E and Stable Diffusion.

(i) **Resource Creation:** Midjourney allows teachers to create visual exemplars and resources within seconds. This capability directly impacts teacher wellbeing and productivity by providing access to a wider array of visual options for any given learning objective. AI-generated images can serve as inspiration, exemplification, or prompts for discussion, making them versatile teaching aids.

Figure 1.
Examples from Midjourney

(ii) **Differentiation:** The speed of image creation with Midjourney enables teachers to react quickly to the needs of their lessons. For example, in a lesson focused on understanding and applying construction lines in sketching, a teacher used Midjourney to create a bespoke exemplar featuring a 'Star Wars' theme, engaging and motivating learners who were fans of the franchise (Figure 2). This ability to tailor resources in real-time enhances student engagement and learning outcomes.

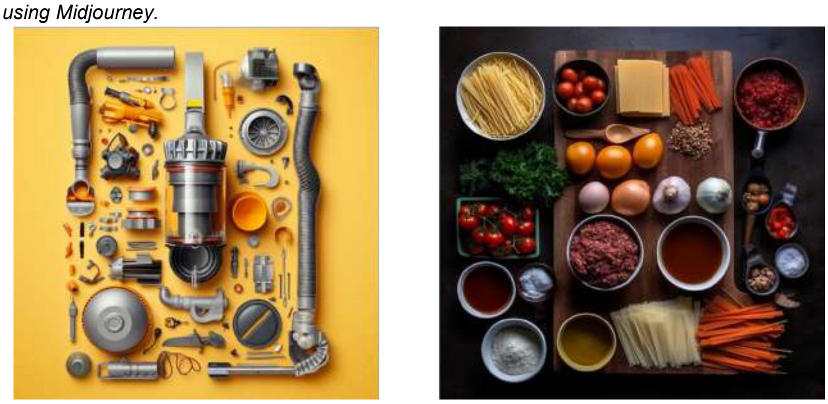
Figure 2.
Example of Star Wars themed design ideas with Midjourney.

(iii) **Prompting a Persona:** Gen-AI tools allow users to alter the persona of the output creator within the prompt. For instance, when using text-to-text models like ChatGPT, the written output can be tailored to a specific reading age or style. Similarly, with image generators, teachers can create exemplars suited to specific age groups. An example prompt might be: 'Create a colourful poster about sustainability designed by an 8-year-old at school,' resulting in age-appropriate educational materials (Figure 3).

Figure 3.
Creating age-appropriate artwork using Midjourney.

(iv) **Knolling:** Images created with the term 'knolling' are particularly useful for D&T teachers (Figure 4). Knolling involves arranging items neatly at right angles, often in a grid or parallel lines, making it easy to see all items clearly. Originating in the 1980s from a furniture shop practice inspired by Knoll furniture's clean lines, this method is now popular in photography, art, and organisation. Using knolling prompts can produce tidy, organised images ideal for classroom discussions.

Figure 4.
Example of 'knolling' using Midjourney.



3.2. Padlet

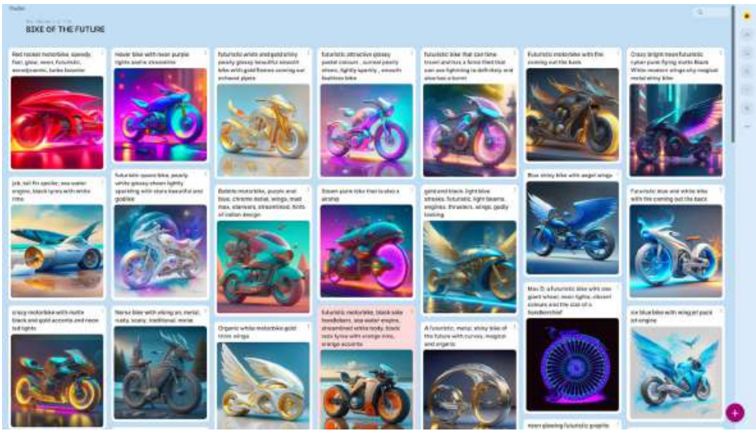
Padlet is an essential educational tool with a dynamic platform for sharing and assessing student work. Its 'post-it' style interface facilitates the sharing of visual content, fostering collaboration and peer assessment. The recent addition of an AI-powered function, 'I can't draw', enables students to generate images from prompts, enhancing creativity and descriptive skills. Despite suggestions to rename this feature to encourage drawing skills positively, its current functionality supports imaginative exercises and discussions.

Padlet has significantly impacted teaching and learning, particularly during the remote learning phase of the pandemic. Its gallery or pinboard interface allows instant sharing of work, fostering a collaborative and interactive classroom environment. For D&T teachers, Padlet is especially beneficial for displaying visual content, such as photographs of practical work or design drawings, enabling real-time sharing on devices and classroom screens.

(v) **Peer Assessment:** Padlet supports peer assessment by allowing teachers to set criteria for students to assess each other's work through live comments. This promotes critical thinking and feedback skills, enhancing learning outcomes and building a sense of community among students.

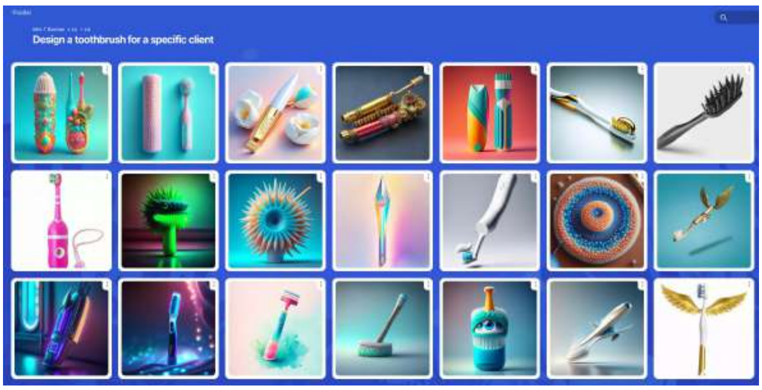
(vi) **AI Functionality:** The 'I can't draw' feature leverages AI to generate images from textual prompts provided by students, encouraging the use of descriptive vocabulary and creative thinking. The tool produces six generated images rapidly for students to choose from and share.

Figure 5.
Examples from Padlet



Example Activity 1: In one activity (Figure 5), students were asked to imagine a 'bike of the future from the year 2100'. After sharing their ideas verbally with a partner, they summarised their descriptions into written prompts and chose images that most closely resembled their vision. This activity enhanced their descriptive vocabulary and set a creative tone for the lesson.

Figure 6.
Examples of toothbrush ideas from Padlet.

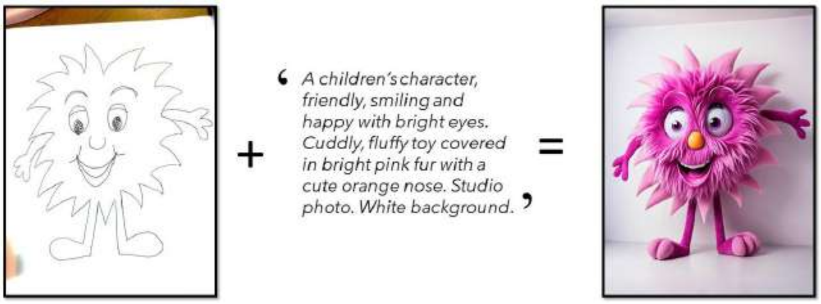


Example Activity 2: Another activity (Figure 6) involved students designing toothbrushes for specific clients without revealing the clients' identities. This prompted discussions about the intended clients based on the generated images, enhancing analytical and deductive reasoning skills. This approach was used to teach ergonomics and anthropometrics, facilitating rich discussions and focused learning outcomes.

3.3. Newarc.ai

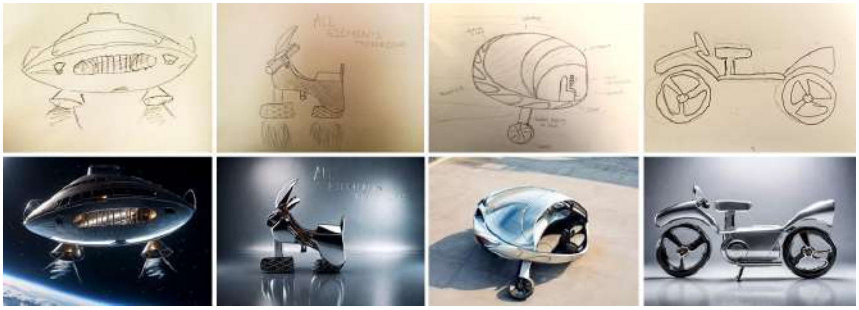
Newarc.ai is an image-to-image Gen-AI tool that can transform an input image and a written prompt into a refined outcome (e.g. Figure 7). Offered free for educational purposes, Newarc.ai is highly valued in the fashion and footwear industries for its ability to render fabrics and materials to a very high standard.

Figure 7.
Example of image-to-image development from Newarc.ai.



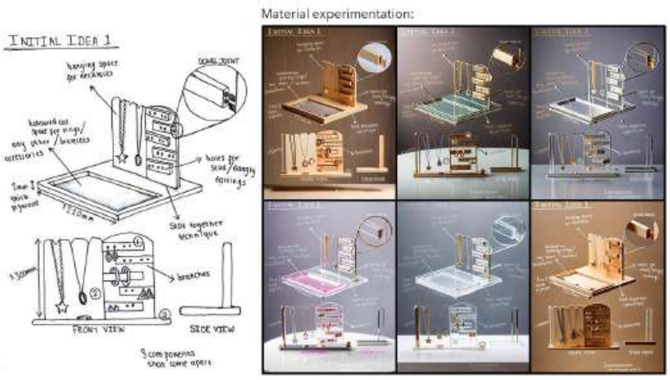
(vii) **Engagement and Encouragement:** In D&T education, many students believe they lack drawing skills or creativity. Newarc.ai has proven effective in overcoming this barrier. For example, year 8 students sketched outlines of future vehicles (Figure 8), which were then scanned into Newarc.ai. Discussions about materials led to descriptive prompts, and the resulting images gave students a sense of achievement and pride in their designs.

Figure 8.
Example of turning drawings into images from Newarc.ai.



(viii) **Iterative Design Process:** For older students, Newarc.ai is integrated into the iterative design process, allowing experimentation with materials and aesthetics. The tool's ability to provide multiple options and fine-tune specific parts of an image facilitates rapid trial and error, aiding decision-making (Figure 9).

Figure 9.
Example of idea development using Newarc.ai.



(ix) **Augmenting Designs:** Newarc.ai allows users to alter the background 'world', light quality, or time of day in their rendered images. CAD models can be input and rendered in various materials and locations, enhancing the design process (Figure 10).

Figure 10.
Example of augmentations from Newarc.ai.

(x) **Textiles and Fabric Rendering:** Primarily used by professional fashion and footwear designers, Newarc.ai excels in rendering fabrics to an incredibly high quality. The output images reflect not only the aesthetics but also the weight and drape of the fabrics, making it an invaluable tool for textile and fashion design education (Figure 11).

Figure 11.
Example of fabric rendering of a fashion design from Newarc.ai.

3.4. Summary

The integration of AI tools like Midjourney, Padlet, and Newarc.ai into D&T education offers significant benefits. These tools enhance resource creation, student engagement, and the iterative design process, providing teachers and students with innovative ways to explore and develop their creativity and skills. The use of these advanced technologies fosters a more interactive and collaborative learning environment, leading to improved educational outcomes. Having explored examples of how Gen-AI is being and can be used in the classroom, in the next section we will explore the findings from the survey of teachers of D&T.

4. FINDINGS

The online survey was organised into four (4) sections: demographic information; general information; experience of AI in general; and use of AI to support the teaching of design and technology.

4.1. Demographic Information

19 participants completed the questionnaire, all of whom confirmed that they were practicing teachers; 14 (73.68%) participants identified and male (sex) and man (gender) and 5 (26.32%) as female (sex) and woman (gender); 16 (84.21%) identified as heterosexual and 3 (15.79%) Homosexual; and 16 (84.21%) selected their ethnicity as 'White: English, Welsh, Scottish, Northern Irish or British', 1 (5.26%) as 'White: Any other White background', 1 (5.26%) as 'Asian or Asian British: Indian', and 1 (5.26%) as 'Mixed or multiple ethnic groups: White and Asian'. The majority work in secondary schools only (17 / 89.47%), with 1 (5.26%) working on further education (18 years +) and 1 (5.26%) across all phases from primary to on further education. Table 2 indicates that almost two thirds of the participants were aged between 35 and 54 years, and the years in-service ranged from 4 to 35 years in teaching.

Table 2.
Age Range

Age	No.
25-34 years	3
35-44 years	6
45-54 years	6
55-64 years	3
65-74 years	1

4.2 General Information

Table 3 illustrates a very high level of awareness of using AI embedded in other applications (e.g. grammar checks in word processing packages), with only 10.53% (n=2) indicated that they were never aware of it. Whereas Table 4 shows a relatively lower level of engagement with Gen-AI, with 10.53% (n=2) rarely and 15.79% (n=3). Nevertheless, over half of the participants regularly engage, at least once a day (36.84%) or week (26.32%). There is slightly higher level of familiarity (Table 5) compared with usage (Table 4), indicating that knowledge of Gen-AI does not necessarily lead to use. Regarding confidence, there is a swing towards the middle of the range, with 21.05% admitting that they are somewhat unconfident. This suggests a tendency towards experimentation and a relative lack of barriers to engagement.

Table 3.
Q11 How frequently are you aware of using AI that is embedded into other applications?

Frequency	Percentage
at least once a day	57.89%
at least once a week	21.05%
at least once a month	10.53%
rarely	0.00%
never	10.53%

Table 4.
Q13 To what extent do you use generative AI?

Frequency	Percentage
at least once a day	36.84%
at least once a week	26.32%
at least once a month	10.53%
rarely	10.53%
never	15.79%

Table 5.
Q12 How familiar are you with Generative AI?

Familiarity	Percentage
very familiar	26.32%
somewhat familiar	47.37%
neither familiar nor unfamiliar	10.53%
somewhat unfamiliar	10.53%
very unfamiliar	5.26%

Table 6.
Q14 How confident are you using generative AI?

Confidence	Percentage
very confident	15.79%
somewhat confident	52.63%
neither confident nor unconfident	5.26%
somewhat unconfident	21.05%
very unconfident	5.26%

4.3 Experience of AI in general

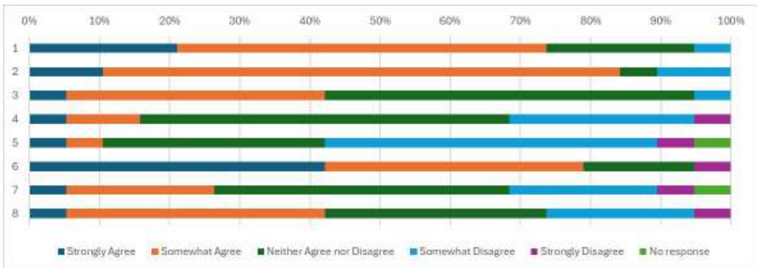
In this section, participants were asked to respond to eight (8) general statements about AI in education (Table 7), which were drawn from a study by Ofosu-Ampong et al. (2023).

Table 7.
Acceptance of Artificial Intelligence in Education Statements (Ofosu-Ampong et al., 2023)

Q15.1 I trust in the value, accuracy and benefit expected from the use of AI systems in education.
Q15.2 I trust in the accessibility and user-friendliness of AI systems.
Q15.3 I trust AI technology and its decision-making capabilities.
Q15.4 I trust in the transparency and explainability of AI systems.
Q15.5 I trust in the privacy and data security measures in place for the use of AI systems.
Q15.6 I have a previous positive experience with the use of AI systems.
Q15.7 I trust in the social and ethical implications of the use of AI systems in education.
Q15.8 I trust my authorities to put in place criteria for the ethically acceptable use of AI.

The participants indicated (Table 8) a very high level of acceptance of the value, accuracy and benefit expected from the use of AI systems in education (Q15.1: 21.05% strongly agree, 52.63% somewhat agree), and has having previous positive experience with the use of AI systems Q15.6: 42.11% strongly agree, 36.84% somewhat agree). Whereas trust in the transparency and explainability (Q15.4: 5.26% strongly agree, 10.53% somewhat agree) and the privacy and data security measures in place for the use (Q15.5: 5.26% strongly agree, 5.26% somewhat agree) of AI systems showed a markedly different picture, illustrating potential uncertainties around this emerging technology.

Table 8.
Responses to Acceptance Statements



4.4 Use of AI to Support the Teaching of Design and Technology

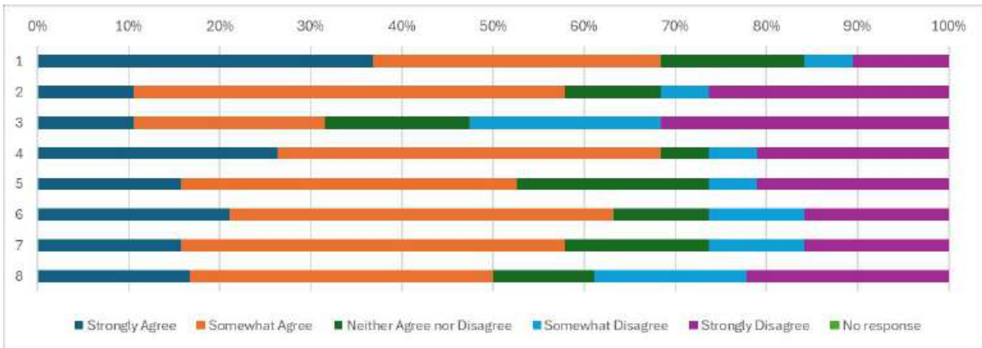
In this section, participants were asked to respond to another eight (8) statements focused on the use of AI to support the teaching of design and technology (Table 9).

Table 9.
Use of AI to Support the Teaching of Design and Technology Statements

Q16.1 I use AI to complete admin tasks more efficiently.
Q16.2 I use AI to plan my lessons.
Q16.3 I use AI for feedback and marking.
Q16.4 I use AI to create teaching and learning resources.
Q16.5 I use AI as a pedagogical tool with pupils in the D&T classroom.
Q16.6 I teach about how to use AI in the D&T classroom.
Q16.7 I use AI to enhance the traditional pedagogical approaches I use.
Q16.8 I use AI to create novel pedagogical approaches.

In terms of acceptance, the responses from the participants (Table 10) indicates that the use of AI to complete more routine administrative task more efficiently was higher (Q16.1: 21.05% strongly agree, 52.63% somewhat agree) than for its use to create novel pedagogical approaches (Q16.8: 5.26% strongly agree, 36.84% somewhat agree). However, with this group of participants approximately half were positive in their agreement, which is taken as a proxy for engagement and acceptance. The statement where there was a notably lower level of agreement was Q3: I use AI for feedback and marking. This may be in response to the elevated levels of anxiety in the education system around AI and academic malpractice at present.

Table 10.
Reponses to Design and Technology Focused Statements



4.5 Correlations

The Pearson Correlation Coefficients (r) show eight (8) strong positive relationships (r > 0.8) between seven (7) of the quantitative questions/ statements in the questionnaire. The correlations suggest that the following AI trends go hand-in-hand:

(i) positive experiences and frequency of use;
(ii) frequency of use and confidence levels;
(iii) confidence levels and explicit teaching about how to use;
(iv) confidence levels and use to enhance traditional pedagogical approaches;
(v) use to produce resources and use as a pedagogical tool with pupils;
(vi) use to produce resources and use of AI for enhancement;
(vii) use as a pedagogical tool with pupils and use to enhance traditional pedagogical approaches;
(viii) explicit teaching about how to use and use to enhance traditional pedagogical approaches.

So, positive experience, frequent use and higher confidence levels appear to correlate (i, ii & iii), reflecting the findings of Andrews, Ward, and Yoon (2021). Whilst there is no clear causal relationship, it could be inferred that this cluster of factors influences the explicit teaching of how to use AI in the D&T classroom (viii) and as an enhancement to traditional pedagogical approaches (iv), aligning with Yawson's (2024) principle of substantial equivalence. Therefore, an emergent adoption framework should begin with addressing success and confidence through frequent and exploratory use of Gen-AI in the D&T classroom. The second level incorporates Gen-AI into current practices, adapting approaches to lesson planning, teaching methods and curriculum content. An aspirational third level, but as yet not represented in the higher correlated statements, might include the creation of new and novel practices. However, with the emergence of examples, such as those presented in Section 3 (above), alongside rigorous intellectual critique and empirical research, the pragmatic nature of teachers of D&T subjects will no-doubt embrace, adopt and adapt this new technology. Difficult questions need to be asked to probe and test the benefits and limitations of Gen-AI. One such difficult question is around the tendency for Gen-AI to draw on archetypal motifs, such as the stereotypical profile of a motorcycle in Figure 8 or rocket as in Figure 10. Albeit in critique of product analyses and the negative impact of a narrow focus on artifacts that have the same function as potential design solutions on creativity, McLellen and Nicholl (2011) state in the title of their article "If I was going to design a chair, the last thing I would look at is a chair"! Therefore, a key question the critically engaged Gen-AI adopter might ask themselves is "If the whole class produces ideas or solutions that look very similar, are they really being creative?" – i.e. Might Gen-AI provide an illusion of creativity, by presenting interestingly decorated templates? As suggested in the examples above, one way to address this apparent flaw and dispel illusions is to expand pupils' AI literacy, creative vocabulary and thinking skills.

5. CONCLUSION

Moving towards an acceptance framework for Gen-AI in technology education, the brief discussion of the questionnaire findings above, indicates that teacher adoption in D&T follows similar patterns to other disciplines. However, a limitation of this study was the small sample size, with the high level of acceptance, indicating potential self-selection or volunteer bias. Therefore, the next step would be to undertake a larger-scale survey of teachers. Nevertheless, the findings offer a key insight into the behaviours of early adopters, such as a willingness to experiment with limited prior knowledge and create early successes to build confidence. There is, of course, a risk of an uncritical adoption of Gen-AI, without asking difficult questions. However, this should not be a barrier, but an enhancement to experimentation and creative adoption. Teachers of D&T who want critically to engage with Gen-AI might use SWOT analysis to critique the strengths, weaknesses, opportunities and threats associated with the ten (10) capabilities identified in the examples (Section 3), alongside established 'signature' and groundbreaking emerging pedagogies.

In response to the findings from this study, and with an eye on policy developments in the public domain (e.g. DfE, 2024), the following principles are proposed as a starting point for scholarly discussions on an emergent Gen-AI acceptance framework for D&T and other technology education subjects:

(i) Understanding the benefits and limitations of Gen-AI in both the general and subject specific contexts for teachers of D&T;
(ii) Frequent, heuristic, and critical use of Gen-AI to support routine administrative tasks to improve efficiency;
(iii) Explicit teaching about the use of Gen-AI in D&T curriculum, including issues relating to ethical and responsible use;
(iv) Open and collaborative development of subject specific approaches to Gen-AI in D&T practice, including co-creation with teachers and learners;
(v) Use of Gen-AI to adapt and enhance established pedagogical techniques and approaches;
(vi) Experimentation and evaluation of new Gen-AI inspired pedagogical techniques and approaches;
(vii) Continuous evaluation of Gen-AI in the D&T curriculum, and as an administrative and pedagogical tool;

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Teaching Strategies for Cultivating High- order Thinking skills in Technology and Engineering Education

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Abstract

Developing students' high-order thinking skills are core goals of technical and engineering education. Based on Bloom's cognitive goal classification theory, this paper defines the high-order thinking skills to be developed in technical and engineering education as aiming at solving real-life authentic problems, and in the process of solving the problems, the students' abilities such as problem solving, integrated decision making, critical thinking and creative thinking are enhanced. At the same time, students' curiosity, inquisitiveness, and other thinking tendencies are developed. On the basis of analyzing the components and formation process of high- order thinking skills in technology and engineering, this paper proposes four teaching strategies for the cultivation of high-order thinking skills: using real situations to stimulate students' interest and provoke their thinking; using core experiences to lay a good foundation for high-order thinking skills; using evaluation frameworks to visualize high-order thinking skills; and using core tasks to drive students' deep learning.

Key Words teaching strategies, high-order thinking skills, technical and engineering education

1. HIGHER-ORDER THINKING FOSTERED BY TECHNICAL AND ENGINEERING EDUCATION

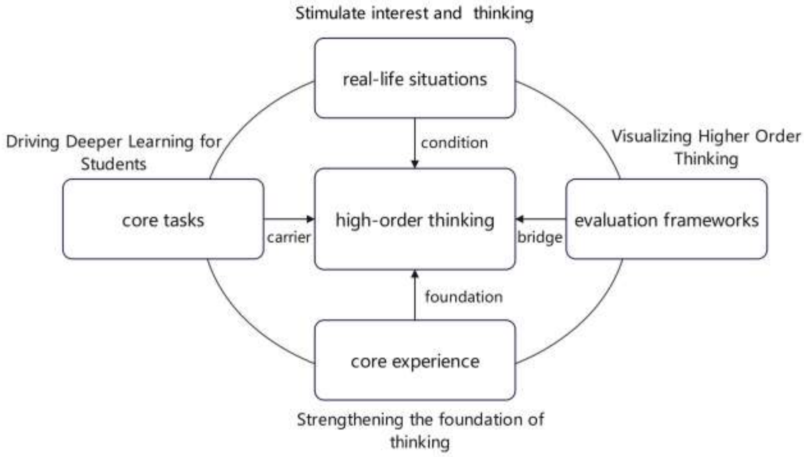
Technology and engineering education advocates the creation of authentic contexts that guide students to apply multidisciplinary knowledge of technology and engineering to solve real problems, transforming the knowledge and skills students learn into a process of inquiry into different aspects of the interconnectedness of the world, and thus fostering creativity, collaborative communication, critical thinking, real-world problem solving skills, and social responsibility in ill-structured learning contexts(Qi Meiling,2013) . The development of higher order thinking in students is one of the core goals of technical and engineering education. Bloom's Taxonomy of Educational Objectives is widely used to distinguish between lower and higher order thinking skills. Six types of cognitive processes are included: (1) remembering, (2) understanding, (3) applying, (4) analyzing, (5) evaluating, and (6) creating. These six thinking processes are a continuum of constant cognitive complexity. Of these, analyzing, evaluating, and creating are referred to as higher order thinking skills(Anderson, L. W. & Krathwohl, D. R.,2001) . In engineering design activities, students use analysis to identify clear problems; trade-offs to compare and evaluate different design alternatives and make comprehensive decisions; design to create prototypes or models adapted to specific contexts; and evaluation to identify deficiencies in existing solutions and continue to optimize and iterate. These learning processes reflect the unique value of technical and engineering education for the development of higher-order thinking in students.

Combining Bloom's classification of goals and the characteristics of technology and engineering education, the article defines higher-order thinking in technology and engineering education as being aimed at solving real engineering problems, and in the process of problem solving, what students acquire are higher-order cognitive skills, and their analytical, evaluative, and creative abilities are enhanced. At the same time, students' curiosity, inquisitiveness and other thinking tendencies are developed.

2.INSTRUCTIONAL STRATEGIES FOR TECHNOLOGY AND ENGINEERING EDUCATION TO PROMOTE THE DEVELOPMENT OF HIGHER-ORDER THINKING

The higher-order thinking that technology and engineering education seeks to foster is closely related to classroom elements. Among them, the core experience (disciplinary and related knowledge and methodological knowledge) is the foundation for higher-order thinking; the authentic context is the condition for higher-order thinking; the core task is the driving force for higher-order thinking, and the evaluation framework is the mediator for higher-order thinking. Based on this, the article proposes teaching strategies to cultivate higher-order thinking: stimulate interest in thinking with authentic contexts; consolidate the foundation of thinking with core experiences; visualize higher-order thinking with evaluation frameworks; and drive in-depth learning with core tasks.

Figure 1.
Teaching Strategies for Higher Order Thinking in Technology and Engineering



2.1. Stimulating interest in thinking with real-life situations

Problems in authentic contexts are real problems and contextual vectors captured from the real world and derived from people's productive practices. Because of their natural relevance to students' lives, students are often attracted to these "my problems" and are interested in exploring them further. Moreover, creativity is human nature, and solving problems in the field of technology and engineering means that they can be designed and created like engineers, which undoubtedly further stimulates students' motivation to participate in them. In addition, the complexity of engineering problems in real situations determines that simple thinking and fragmented knowledge are not good enough to cope with them, but require the use of multidisciplinary knowledge, the ability to invoke thinking and other comprehensive abilities, the investment of emotion and will, and sustained efforts to solve them. Learning in the process of exploring real-world problem solving enables learners to engage in meaningful and purposeful activities like practitioners, and to effectively transfer and apply the knowledge and experience gained to solving social life problems(Cai Yaping,2011).

It can be seen that the real situation makes students experience the connection between learning and the real world, stimulates students to be needed and sense of value, stimulates the intrinsic and extrinsic motivation to learn, and is a necessary condition for the occurrence of higher-order thinking. However, the current contextual teaching has the following problems: (1)only play the function of introduction, lack of penetration. (2) far away from the students, context and teaching content, teaching objectives detached, lack of relevance, purpose.(3)context fragmentation, superficial, lack of fluency and systematic. Technology and engineering context requires the context to have permeability, to ensure that the problem design can be transitioned from lower-order thinking to higher-order thinking, to ensure the coherence of students' thinking, and to realize the goal of the development of higher-order thinking in deep learning. To study the unit teaching of the lesson "Into the world of technology", starting from the unit learning objectives, choose from the "compass to the BeiDou satellite navigation system" throughout the unit, and strive to realize the context of the teaching of permeability, openness, and nurturing, through the context (activities) and the main line of the problem (knowledge) to achieve the organic integration of the context and the content, to achieve the unit learning objectives. Integration of context and content through the main line of context (activities) and the main line of questions (knowledge) to achieve the unit learning objectives.

2.2. Strengthening the foundation of thinking with core experience

Higher-order thinking is not to disregard the learning of knowledge and skills, but to embody the teaching concept of "teaching for use, learning for use", and to apply knowledge and skills to solve technical and engineering problems. In the contextual teaching of technology and engineering, there is a contextual main line and a knowledge main line. How to integrate the two main lines organically is the difficulty of contextual teaching. The main line of context serves the main line of knowledge, and the organic integration of the main line of context and the main line of knowledge is realized in the form of contextual tasks and problem exploration in context, which is conducive to students' independent understanding of knowledge and construction of meaning.

Students move into specific problem situations with their existing knowledge, skills, and other core experiences. While the requirement for higher-order thinking is present throughout the activity, it is clear that higher-order thinking alone will not produce a satisfactory piece of work. The completion of a piece of work requires students to design, build, test, and iterate on scientific principles, understand the properties of materials, learn to use woodworking, metalwork, and electronics, and apply technical and mathematical knowledge and skills. But knowledge and skills alone are not enough; knowledge and skills help students complete their work, but they need the added benefit of higher-order thinking if they are to complete their work at a high level of quality. Based on this analysis, teachers often turn unit content into engineering projects, using engineering design tasks as a guide to drive students' active learning of knowledge and skills. This is then used to analyze the problem and solve it creatively, and to evaluate the rationality and shortcomings of the solution. This realizes the organic integration of the main line of context and the main line of knowledge. For example, the project of automatic watering device integrates the content of the knot control and its design unit, based on analyzing the degree of plants' need for water, using the characteristics of atmospheric pressure to design a practical, intelligent and creative watering device.

2.3. Visualizing higher-order thinking with evaluation frameworks

The Technology and Engineering Higher Order Thinking Skills Assessment Framework facilitates the development of higher order thinking. The higher-order thinking ability evaluation framework is an important basis for classroom observation, a criterion for determining whether higher-order thinking occurs, and plays a guiding and evaluating role in developing students' higher-order thinking. As shown in Table 1, technical and engineering education is centered around engineering problem solving, which requires different thinking skills at different stages, and at the same time this provides an important opportunity for students to develop higher-order thinking skills. For example, in the Clarifying the Problem stage, students need to be able to gather information, investigate, analyze, and determine the problem to be solved and the constraints to which it is subject. At the stage of conceptualizing a solution, it is necessary to objectively consider various factors on the basis of design analysis, apply common innovative methods, present and express a design solution in terms of drawings and symbols.

Table 1.
Framework for evaluating higher-order thinking skills in technical and engineering education

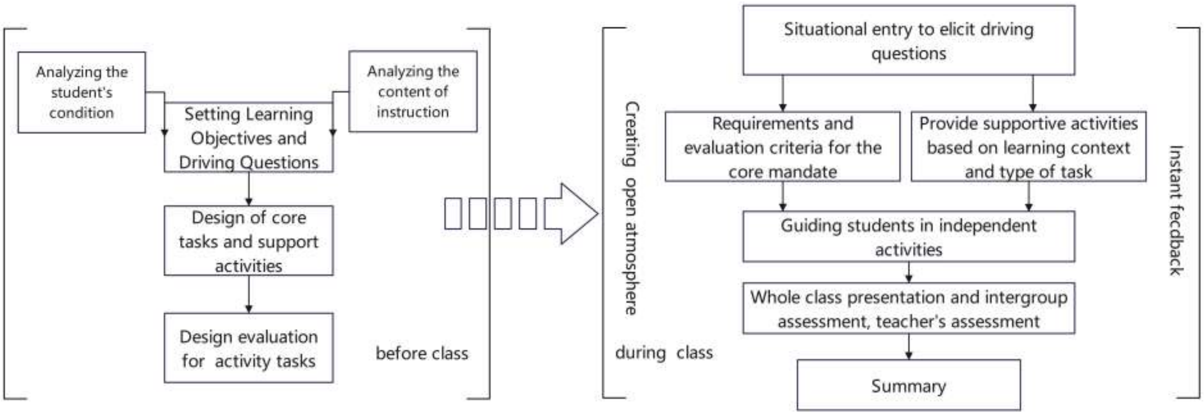
Learning content	Higher order thinking skills	Student performance
Define problems	Information gathering, investigation, analysis, and judgment	Facing the appropriate technical situation, identifying the problem to be solved and analyzing the constraints to solving it
Design analysis	Design Analysis, Presentation and Explanation	Be able to analyze the design by considering objects, people, and environment, and present and express the mind map of the design.
Conceptualize the design	Analysis, design, presentation	On the basis of design analysis, objectively consider various factors, apply common creative methods, and present and express design solutions with drawings and symbols, etc.
Selection and optimization of solutions	Analyze, compare, question, weigh, evaluate, select, decide, design	Analyzing, comparing, weighing and evaluating their own and others' design solutions at different stages, finally selecting the design solution that meets the design requirements and general principles of design, and optimizing and refining the solution.
Modeling	Analysis, selection, decision-making, design, implementation	Analyze the design scheme, select materials (planning materials) and tools according to the requirements of the scheme, determine the time sequence and process for the realization of the scheme, and complete the production of the model.
Technical testing and optimization	Design, implement, analyze, extrapolate	Design simple technical tests, be able to perform basic technical tests and technical index measurements on models or products, and write reports on simple technical tests and program tests. Identify and analyze problems and optimize solutions.
Writing instructions	Analysis, design, selection	Write product specifications based on product and user needs

2.4. Deep learning driven by core tasks

The development of higher order thinking in technology and engineering education is driven by core tasks. The process of students completing the chain of core tasks along the solution of driving problems is an important process for the cultivation and formation of students' higher-order thinking. With the ultimate goal of implementing core literacy, the core tasks take project tasks as the carrier, create real situations that can trigger driving problems, and design the core task chain with the solution of driving problems as the clue. Supporting activities are designed to address the needs of the core tasks, i.e., to supplement the "shortcomings" of students in completing the core tasks, and to acquire the knowledge, skills and methods required for completing the core tasks. With the gradual completion of the core task chain, higher-order thinking occurs, and students' technical awareness, engineering thinking, innovative design, drawing expression, and materialization ability are continuously improved, so that the core technology and engineering literacy can be implemented.

The specific implementation process, including two parts, before and during the lesson. Before the lesson, the teacher selects appropriate engineering projects according to the curriculum standards and students' learning situation and social life, and transforms the curriculum standards into learning objectives. Then, using the objectives as a guide, the teacher designs driving problems, breaks down the driving problems, and designs core tasks that can solve the sub-problems. In the lesson, the teacher creates a real situation so that students naturally enter into the situation, sets up tasks along the core task chain, and puts forward the task requirements and the evaluation criteria for reaching the task requirements, and then provides supportive activities according to the type of task and the actual situation of the students. Students begin to carry out activities independently as individuals or in small groups, while the teacher visits the classroom to guide and help students complete the tasks. Afterwards, the teacher organizes whole-class presentations and exchanges, invites group representatives to share their milestones, and carries out inter-group and intra-group self-assessment. Teachers will make timely comments and summarize at the end.

Figure 2.
Core mission map



Some teachers used the Fishbone Diagram for engineering activity design and presentation. "The fishbone diagram solves the confusion between core tasks and learning scaffolds (supporting activities). The pre-course design has built a framework for driving task design (fishbone diagram), which provides a clear picture of the driving questions, the core tasks, and what supporting activities are needed for which core task. Supporting activities are the construction of knowledge, skills, and methods, while core tasks are closer to the formation of higher-order thinking. In the process of teaching and implementation, to avoid the previous supportive activities as the focus, students get more subject knowledge and skills, but ignore the completion of the core tasks, so that the formation of competence and literacy fall through.

3. CONCLUSION

Technology and engineering education plays a crucial role in developing higher-order thinking in students. The instructional strategies presented in this paper enable students to be immersed in complex and changing real-world problems, stimulating their desire for exploration and creativity. The core experience-based approach ensures that students are able to build a solid thinking framework while mastering basic knowledge and skills. The visualization of the assessment framework provides a clear standard for teachers and students to measure and promote the development of higher-order thinking. The core tasks guide students to deepen their understanding and application of knowledge and skills in the process of solving real-world problems, thereby enhancing their overall problem-solving, decision-making, critical thinking and creative thinking skills. These teaching strategies are interrelated and complementary, and together they constitute an efficient and systematic system for the cultivation of higher-order thinking, which provides strong support for the high-quality development of technology and engineering education.

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Promoting UAV autonomous aerial video to improve cross-cultural understanding, historical knowledge, and students' perception

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Abstract

We designed a cross-cultural learning activity leveraging unmanned aerial vehicle (UAV) technology to enhance historical and cultural understanding among twenty university students from Indonesia and China. By recording and exchanging aerial videos of local cultural and historical sites using UAVs equipped with the latest AI features, students gained unique perspectives on these landmarks, unavailable through traditional ground-level photography. This study examined how such activities foster cross-cultural understanding and deepen historical knowledge alongside participants' perceptions of UAV video production. Employing a mixed method approach, including video analysis, questionnaires, and interviews, we discovered that UAV technology not only facilitated a unique learning experience but significantly impacted participants' cross-cultural and historical insights. The ease of UAV use and its effectiveness in cross-cultural education were particularly noted, with participants expressing intentions to use UAV technology in future learning contexts. Based on these findings, we offer recommendations for educators and researchers to integrate UAV technology into educational settings.

Key Words: Cross-cultural understanding, Historical knowledge, Unmanned aerial vehicle, autonomous aerial video, Perceptions

1. INTRODUCTION

In recent decades, the low cost of international communication and our ability to automate processes worldwide have made the world genuinely global (Akdere et al., 2021). Designing instructional skills to develop skills such as cross-cultural understanding, historical knowledge, positive perceptions, and behavioral intention to any new technology are urgently needed. Educational technologies have opened a wide range of opportunities for universities to create content such as photography, films, or videos that can be shared to interact with people from targeted cultures in intercultural learning. Artificial intelligence, such as an unmanned aerial vehicle (UAV), gets more attention (Kao et al., 2023; Lai, 2023; Shadiev & Yi, 2023). Unger et al. (2019) mentioned that students could collect videos and photos at a low cost when UAVs are employed. Shadiev et al. (2023b) suggested that students can create cultural content, such as photos and videos in their local communities, and then share them with their partners from other countries.

In today's globalized society, cross-cultural understanding and historical knowledge are considered twenty-first-century skills and essential abilities. However, few studies have used UAVs in the cross-cultural learning context to develop cross-cultural understanding, historical knowledge, and participants' perceptions of UAVs. To bridge this gap, the present study explores the affordances of UAVs' aerial filming for cross-cultural learning and how learning activities supported by UAVs can develop cross-cultural collaborative learning, historical knowledge, and participants' perceptions of UAVs. The study aimed to address the following three research questions (RQs): (RQ1) To what extent did the learning activity promote the development of cross-cultural understanding supported by UAV autonomous aerial video? (RQ2) How can the learning activity facilitate historical knowledge for Chinese and Indonesian participants? and (RQ3) What were participants' perceptions of UAV?

2. LITERATURE REVIEW

2.1. Cross-cultural understanding

Cross-cultural understanding is the essential ability to correctly recognize, understand, and interpret various types of cultural information, e.g., history, languages, and traditions (Shadiev et al., 2019). Various theories have been proposed to acquire cross-cultural understanding; one of the most particular theories is cultural convergence (Gudykunst et al., 1988; Kincaid, 1979). Cultural convergency theory means two or more participants reach a mutual understanding of culture and the world culture they live in through communication and information exchange (Gudykunst et al., 1988; Kincaid, 1979). Talalakina (2010) suggested measuring cross-cultural understanding by following four rubrics: (a) cross-cultural knowledge is the ability to accustom to different cultural values, beliefs, characteristics, and behaviors; (b) cross-cultural sensitivity is the ability to read into situations, behaviors, and contexts that are culturally rooted and to react to the interlocutors appropriately; (c) cross-cultural competence is the ability to work across cultures to respect different cultures, adapt to changing the situation, and benefit from them; and (d) cross-cultural awareness is the ability to understand and appreciate other's cultures. Cross-cultural learning is a process that enables an individual to acquire new knowledge, techniques, attitudes, skills, and values with respect and awareness of different cultures as the result of participation, exchange, and experience (Yamazaki & Kayes, 2004).

2.2. Historical knowledge

The origin of all the nations of the earth, their history, cultures, languages, traditions, and lifestyles influenced each other (Saginayeva et al., 2017). According to Byram (2008), skills entailed a holistic understanding and acquiring of a culture's historical, political, and social knowledge, followed by behaviors by these customs in real-time verbal or non-verbal interaction. Byram's assessment model explained historical knowledge as the combination of the ability to learn about different historical places and historical events, the ability to discover the similarities and differences across historical places, the ability to realize that each country has its unique historical event, and ability to learn more about our historical event and places (Byram, 2000).

2.3. Unmanned aerial vehicles

Unmanned aerial vehicles (UAVs), commonly known as drones, are unmanned aircrafts controlled remotely by a human operator or an onboard computer (Shadiev et al., 2024). UAVs can provide vivid and authentic videos in the field (Shadiev et al., 2023b). In addition, the UAVs offered possibilities to make the aerial view process more authentic and detailed (Palaigeorgiou et al., 2017). Providing participants with opportunities to experience cultural diversity through reading, simulations, watching a video (i.e., indirect communication), and interacting with people from different cultures (i.e., direct communication) can facilitate cross-cultural learning (Kohlberg, 1984). Dinmore (2019) suggested creating high-quality video, audio, and subtitles that can be autonomously and universally accessed with high flexibility and accessibility. In the present study, we designed a cross-cultural learning activity between Chinese and Indonesian undergraduate participants to create a UAV autonomous aerial video.

3. METHODOLOGY

3.1. Research design

This study adopted a mixed-methods research approach, which involves collecting, analyzing, and integrating both quantitative and qualitative data within a single study. We analyzed all videos created by participants and their scripts and interviews, which aim to measure the mutual understanding of cross-cultural understanding. To consider historical knowledge as a new variable involved in cross-cultural learning, we utilized the questionnaires specific to historical knowledge and the script to measure the participants' historical knowledge and the interview results.

3.2. Research participants

The setting was twenty Indonesian and Chinese participants. Ten Indonesian participants were undergraduate engineering students from the Institute Technology of Sumatera (ITERA), and ten Chinese were undergraduate educational technology students from Nanjing Normal University. Most participants had no prior knowledge of cross-cultural learning activity or experience using UAVs. The range of participants' age was between 18 and 25 years old. All participants were at intermediate English level and had English proficiency certificates (e.g., TOEFL ITP).

3.3. Learning activities

Shadiev et al. (2018) suggested that cross-cultural learning activity involved self-introduction, creating media content and sharing, and experiencing foreign cultures. The cross-cultural learning activity was designed with the following steps.

Step 1 (Self-introduction). Participants from China and Indonesia were asked to record a self-introduction video, and the duration will be taken during 3 to 5 minutes. Each participant wrote a script containing their name, age, hobby(s), study, degree and major, place of origin, and culture in their place of origin and introduced the topic they selected.

Step 2 (Creating autonomous self-introduction video). Twenty participants created their videos in two different ways. First, participants recorded videos using UAV and explained the situation simultaneously (participants used a recorder to record their own voices). The second way was for participants to record the object according to the script they had already made and record their voices separately. Participants used Adobe Premiere CC 2019 SP to edit, combine their video and voice, and add captions to their videos. The final product videos will be shared with their peers using Google Drive.

Step 3 (Watching peers' self-introduction video). Participants from China and Indonesia watched self-introduction videos. Participants learned from them and reflected on their introduction videos.

Step 4 (Creating cultural-historical video). Participants from China and Indonesia selected ten cultural-historical topics for creating an autonomous UAV aerial video. The participants from China and Indonesia were grouped (i.e., one or two students from China and one from Indonesia). As a result, ten groups were formed, corresponding to one cultural-historical topic. Participants then created the script and took an aerial video using UAVs, following their scripts. The video will be taken for 5 to 6 minutes.

Step 5 (Creating autonomous cultural-historical video). Participants again used Adobe Premiere CC 2019 SP to edit, combine their video and voice, and add captions to their videos. The final product videos will be shared with their peers using Google Drive.

Step 6 (Watching peers' UAV autonomous aerial video). Participants from China and Indonesia watched self-introduction videos that their peers shared. Participants learned from them and reflected on their peers' cultural-historical videos.

3.4. UAV autonomous aerial video

UAV autonomous aerial video approach included a UAV tool and UAV autonomous aerial video production process. The participants used DJI Mini Pro 3 as a UAV to create the aerial videos (Figure 1). For autonomous aerial video creation, participants used Adobe Premiere CC 2019 SP as an editing tool to combine their video and voice and add captions to their videos (Figure 2). After finishing the editing, participants have to export the file to get the final product (Figure 3).

Figure 1.
DJI Mini 3 Pro (left) and controller (right). Photos were taken from the DJI Mini 3 Pro website (https://www.dji.com/uk/mini-3-pro).

Figure 2.
Adobe Premiere CC 2019 SP platform

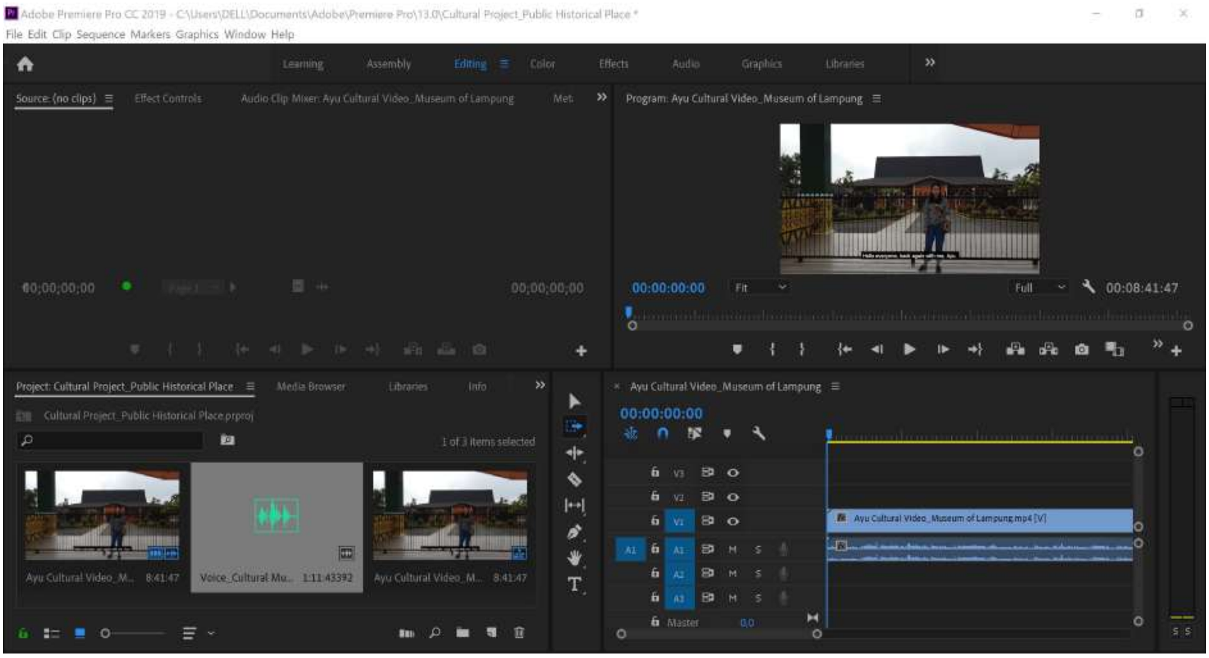
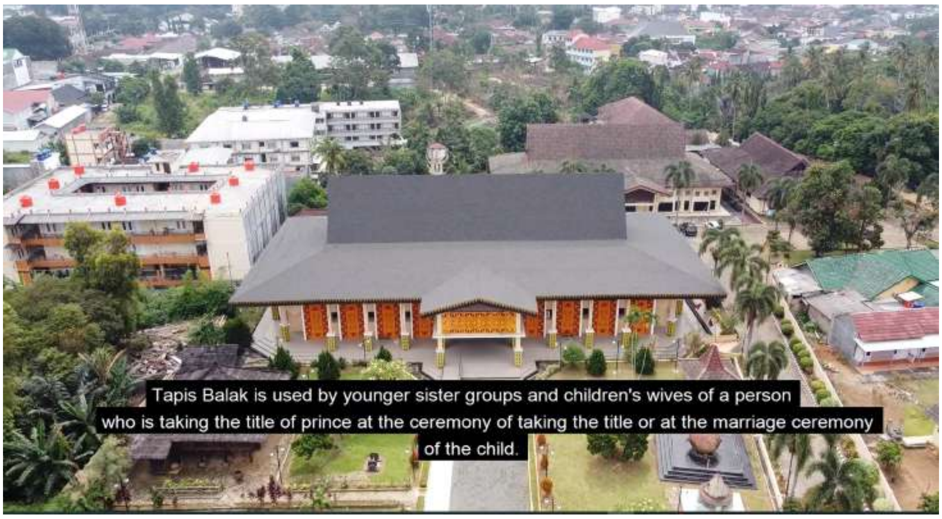


Figure 3.
The final product of UAV autonomous aerial video



3.5. Research procedure

Our study consisted of several stages. Firstly, we recruited the participants and collected their demographic information. In our course, we trained the participants on how to operate and control UAVs for about one week. The next week, we will survey the location and collect the data that will be used to write the script to create the video content. Then, participants recorded their self-introduction and cultural-historical videos in the location based on the selected topic. After taking videos, we guided the participant in editing the video and sharing it with their peers. In addition, we analyzed the scripts, and interviews were conducted to measure their cross-cultural understanding. Finally, we collected post-activity related to historical knowledge using an online questionnaire, script content analysis, and interviews. We also measured participants' perceptions of UAV technology using script content analysis and interviews.

3.6. Data collection

We divided our data collection and analysis into three parts, and the description of the components of the data is presented as follows:

- Cross-cultural understanding. This aspect has three data collection methods (script reports, videos, and interviews).
- Historical knowledge. This aspect has a data collection method with respect to Byram's questionnaires, script reports, videos, and interviews.

Participants' perception. Participants' perceptions included three dimensions (satisfaction, confirmation, and behavioral intention of using UAV). These three dimensions had 12 questions items in total: satisfaction (4 questions), confirmation (5 questions), and behavioral intention (4 questions).

3.7. Data analysis

Cross-cultural understanding (RQ1). We analyzed the script reports and interviews using the cross-cultural understanding scale, which included four rubrics (Talalakina, 2010): (a) cross-cultural knowledge, (b) cross-cultural sensitivity, (c) cross-cultural competence, and (d) cross-cultural awareness. The script reports, videos, and interviews were analyzed using an open-coding approach (Craswell, 2014) based on four rubrics (Talalakina, 2010).

Historical knowledge (RQ2). Questionnaires on Byram's assessment model (Byram, 2000) were used to create the historical knowledge scale and measure historical knowledge as our quantitative data. The Cronbach's alpha value reached values between 0.945 and 0.950 in all of the questionnaires, indicating that the questionnaires' reliability was high. The script reports, videos, and interviews were analyzed using open coding (Craswell, 2014), in which all content in the scripts and videos were read through, text segments in the data relevant to the research questions were highlighted and coded, and the codes with similar meaning were aggregated. All interviews were carried out in English, audio-recorded, and transcribed. Interview transcripts and relevant extractions were reported. The scripts, videos, and interviews were used for the qualitative data analysis.

Participant's perception (RQ3). We conducted one-on-one semi-structured interviews with each participant for approximately 30 minutes to measure satisfaction and confirmation according to a scale developed by Bhattacherjee (2001). We then analyzed the script. All interviews were in English, audio-recorded, and transcribed. The interview results were analyzed using open coding (Craswell, 2014). All codes were gathered into categories of measurements to report the findings. The interview results were used for the qualitative data analysis.

4. RESULT AND DISCUSSION

4.1. Cross-cultural understanding (RQ1)

4.1.1. Cross-cultural knowledge.

Initially, all participants confirmed that they did not know the targeted cultures. After the learning activity, all participants confirmed they gained information about culture, values, and beliefs. Here is one data extraction from Participant 19 (China) related to the "Educational Historical Building" topic:

- If we are going to see the environment, we can see green scenery around the building. This green scenery around Lampung University is because of a tradition of Lampung University, which the Government supports called "Gemah Ripah Loh Jinawi." The spirit of "Gemah Ripah Loh Jinawi" means peace and prosperity and very fertile land.

Data extraction from Participant 9 (Indonesia) related to the "Educational Historical Building" topic:

- These buildings all have red columns, cornices, and large roofs in the style of ancient palaces. If you look carefully, you can see that the ridge of the roof was decorated with a lot of different animal shapes. The main usage of animal ornaments on house ridges is not only for beautiful decoration. Since the Taoist theory of Yin and Yang and Feng Shui held that Yin in these places is heavy and easy to breed dirty things, humans need something to control those dirty things, so the animal ornaments on house ridges were designed.

Participants do not know about their interlocutor's culture and tradition in the interviews. They have no prior knowledge about public historical places in either country. After the learning activity, they have specific knowledge about both countries' cultures and traditions and even more information about the targeted cultures. Interview result from Participant 18 (China) related to the "Public Historical Place" topic:

- I learned some Chinese culture but needed to learn about Indonesian culture. I mainly understand the architectural humanities of Lampung tribes (Saibatin & Pesisir). I learned more information about the Museum Lampung, such as the history of Lampung and the wedding customs there.

Interview result from Participant 8 (Indonesia) related to the "Public Historical Place" topic:

- I have no idea about Chinese culture. After watching the video, I found that The Imperial Examination Museum of China is the only underground museum in China. The museum architecture is square and symbolizes the fairness of the imperial examination system. I mostly learned about the imperial examination system and the harshness of the imperial examination with the attitude of awe.

In this rubric, we explored the scripts, videos, and interview results from two sides (Indonesian and Chinese students) to reach a mutual understanding of cross-cultural knowledge. In the scripts and videos, participants confirmed that they had no prior knowledge about the targeted cultures and traditions at the beginning. After learning activities, participants confirmed that they gained the cultural and traditional information related to their partner. In this study, we find that UAV autonomous video can develop participants' cross-cultural knowledge. This result was relevant to the study of UAV-assisted culturally responsive teaching to facilitate cultural understanding (Lai, 2023).

4.1.2. Cross-cultural sensitivity

Participants need to learn how to respond positively to their peers at our initial interview. After the learning activity, participants can respond with openness to the diversity of culture of their peers. Here is one data extraction from Participant 2 (Indonesia) related to the "Landmark" topic:

- Anyway, Nanjing Radio and Television Tower is a tall building that can be seen in many parts of China. Actually, the tower is a religious building. It is a new type of building in China since Buddhism was introduced to China. To express their devotion to the Buddha, worshippers competed to offer sacrifices, so the "tower," the building where the relic was kept, was built at the right moment.

Data extraction from Participant 12 (China) related to the "Landmark" topic:

- Tugu Juang is one of the monuments of Bandar Lampung and has also become an attractive icon for the community, especially in the city of Lampung. This monument represents the people of Bandar Lampung when it is complex and difficult to fight the beloved country of Indonesia from colonization. I think this is the appreciation of the community of Bandar Lampung by respecting the heroes who have fought for Indonesia, especially Lampung.

In the interview, the participants had no idea about how to respond to their peers with proper attitudes. After learning activities, participants have more positive attitudes and curiosity to respond to the differences they found. Interview result from Participant 17 (China) related to the “Post Independent Era” topic:

- When I found these differences, I wanted to go there personally, feel the local culture and the difference between Indonesia and China, and even live there for a year or two. I heard that Indonesia is a tourist country, so its tourism industry should be significantly developed. I am also very interested in the other characteristics and living habits of people in Pecoh village around Krakatota Monument.

Interview result from Participant 7 (Indonesia) related to the “Post Independent Era” topic:

- I appreciate the differences between cultures because I know that every country will consider different symbols with different meanings. In Indonesia, especially Pecoh Village, there are festivals such as Lomba Makan Krupuk (eating cracker competition) and Panjat Pinang (climbing coconut tree competition). I am still curious about the Mid-autumn Festival celebration at night in Nanjing Yan.

In this rubric, we explored the scripts, videos, and interview results from two sides (Indonesian and Chinese students) to reach a mutual understanding of cross-cultural sensitivity. In the scripts and videos, participants had yet to learn to respond to their peers with positive attitudes at the beginning. After learning activities, participants can respond with openness to the diversity of culture of their peers. In this study, we find that UAV autonomous video can develop participants’ cross-cultural sensitivity. This result is relevant to where UAV allows students to improve their learning interests and confidence (Zhao & Wu, 2022).

4.1.3. Cross-cultural competence

Before the learning activity, participants had yet to learn to reflect on and explore a variety of cultures. After the learning activity, all participants confirmed the skills to reflect, analyze, compare, and respect different cultures. Here is one data extraction from Participant 11 (China) related to the “Environmental Place” topic:

- As I can see there, you are standing on famous cottages on this island, and they call it “Rumah Adat Kebaya”. The most exciting part of this traditional house is the wall. The wall materials are made by Gawok Wood. Gawok wood is expensive in Indonesia. In ancient times, the Betawi tribe who could build Kebaya traditional houses full of Gawok Wood were from wealthy or nobility families. In China, the jade in the flower, Magnolia, represents the noble moral character.

Participant 1 (Indonesia) related to the “Environmental Place” topic:

- In Chinese people’s culture, the bridge is a kind of architecture and a cultural symbol. Bridges represent not only connectivity but also hope for the future. The completion of the Nanjing Yangtze River Bridge not only connected the traffic between the north and the south but also inspired the Chinese people living in poverty at that time to strive for a better life in the future. Betawi ancestors (Indonesia) have created Empang as a local culture since European colonialism a thousand years ago. Empang, or small fish ponds, became the primary source of income for the ancient Betawi tribe.

In the interview, the participants have yet to gain prior knowledge about responding to their peers with awareness. After learning activities, participants have a more positive awareness of cultural differences and similarities between their and targeted cultures. Interview result from Participant 14 (China) related to the “Religion Place” topic:

- First of all, I need to understand my culture enough. Here, I can see a cross symbol. We call it “Salib.” The Cross or Salib is seen as a symbol representing the crucifixion instrument of Jesus Christ and is Christianity’s most famous religious symbol. In this way, when I study Indonesian religious culture, I can judge what is similar and what is different, where the cross symbol is also shown in the church in China.

Participant 4 (China) related to the “Religion Place” topic:

- I admire the cultural differences and similarities of Chinese culture, and I want to continue to learn much more about it. In China, a saying is that one should not worship the Buddha empty-handed. This means it is better not to worship the Buddha in the temple with empty hands. In Indonesia, there are many religions; each religion has its own rules for scarification; for example, Hindus can offer incense, water, fruit, etc. Christian or Catholic followers can sing the name of the Lord over their voices. The most important is sincerity on that scarification. From this explanation, each religion has a unique, which is significantly different.

In this rubric, we explored the scripts, videos, and interview results from two sides (Indonesian and Chinese students) to reach a mutual understanding of cross-cultural competence. From the scripts and the video, participants need to learn to reflect on and explore the variety of cultures before learning activities. In this study, we find that UAV autonomous video can develop participants' cross-cultural competence. Our finding is relevant to developing a competency learning model for students of UAV.

4.1.4. Cross-cultural awareness

Cross-cultural awareness is the ability to understand and appreciate other cultures (i.e., show perspectives and values on the richness and diversity of each culture). Before learning activities, participants needed to learn how to show their perspectives and values to other cultures. After the activity, participants knew how to show their perspective and value to admire others' culture. Here is one data extraction from Participant 13 (China) related to the "Sports Center" topic:

- The association is an essential culture in the Lampung tribe. Manjau Dibingin is also one of the critical traditions and customs for association among Lampungnese young men. Generally, Manjau Dibingin means meeting—young boys with young girls, young girls with young girls, or young boys with young boys. The unique thing in Manjau Dibingin is that the young people have a strong bond in this association. Some of them become best friends, girls, or boyfriends.

Participant 3 (China) related to the "Sports Center" topic:

- The flame and torch of the Nanjing Olympic Stadium have become symbols of the common pursuit of world peace and the highest sporting standards by people of different languages, faiths, and races worldwide. The torch of the Games is elegant and luxuriant, with profound connotations and strong Chinese characteristics. It harmoniously combines Chinese culture with the Olympic spirit. The concept of "harmony" is a unique interpretation of the Olympic spirit and flame.

Initially, participants had no prior knowledge about how to show their behavior to respect other cultures. After learning activities, participants have more positive behavior, thinking, and critical perspective. Interview result from Participant 16 (China) related to the "Pre-independent Era" topic:

- I can discuss Indonesian culture and explain its richness from the video. One unique icon of the Pringsewu region is Bamboo. Each house in Pringsewu decorates its gate with Bamboo. They have a strong reason for this. Bamboo is one of the trees that humans use. In China, we also use Bamboo for many purposes, such as paper, household appliances, etc.

Interview result from Participant 6 (Indonesia) related to the "Pre-independent Era" topic:

- I learned about the culture in China after I exchanged videos. I wanted to know more about Chinese culture and hopefully could go there. Chinese culture, such as the Nanjing City Wall, can be called substantial buildings even though they are old. This is because Porcelain clay Brick is the most significant building material in the Nanjing city wall construction project. The quality requirements of these bricks are very high.

In this rubric, we explored the scripts, videos, and interview results from two sides (Indonesian and Chinese students) to reach mutual understanding in cross-cultural awareness. From the scripts and videos, participants needed to learn how to show their perspectives and values to others' cultures at the beginning of this learning activity. After the activity, participants knew how to show their perspective and value to admire others' culture. In this present study, we find that UAV autonomous video can develop participants' cross-cultural awareness. This result was relevant to the study of UAV-assisted culturally responsive teaching to facilitate cultural understanding and respect (Lai, 2023).

One purpose of this study was to promote participants' cross-cultural understanding in cross-cultural learning activities supported by UAV autonomous aerial video. The results from the script reports, video, and interviews showed that learning activity improved participants' cross-cultural understanding. Instantly, our findings are in line with cultural convergence theory (Gudykunst et al., 1988; Kincaid, 1979). Our results are consistent with those obtained in previous studies, such as Lee and Markey (2014), Psychouli et al. (2020), Sevilla-Pavón (2019), and Shadiev et al. (2021). However, in contrast to the previous study, we employed artificial intelligence technology such as UAV to create a cross-cultural learning environment that can enable participants not only to communicate and exchange cultural-historical information but also to promote a new and unique experience of watching autonomous aerial videos that they never had before.

4.2. Historical knowledge (RQ2)

According to the results in Table 1, the participant scored higher on the post-test items in the historical knowledge questionnaires compared to the pre-test ($p < .005$). The results showed there was a significant increase in the historical knowledge of the participants.

Table 1.
Historical knowledge

#	Items	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	t	Sig (2-tailed)
14	I learned about different historical places of Chinese/Indonesian	2.30	.657	4.35	.587	-9.706	.000
15	I learned about historical event	2.10	.553	4.20	.523	-10.299	.000
16	I discovered the similarities and differences across historical places	2.10	.641	4.30	.571	-11.804	.000
17	I realized that each country has its own unique historical event	2.75	.851	4.35	.489	-6.839	.000
18	I learned more about our historical event and places	2.35	.813	4.35	.587	-8.312	.000

In the script report and videos, all participants confirmed that they had no prior knowledge about any history of China when they began this project. After the learning activity, participants can confirm when they learned about different historical places and historical events and discover the similarities and differences across historical places. Participants from China confirmed that the history of bright colours from Pasar Senin comes from the preference of the Lampung tribe, which like bright colors such as red, yellow, and so on. Here is one data extraction from Participant 20 (China) related to the "Traditional Market" topic:

- As I can see, the buildings of Pasar Seni have many attractive colours. According to Coastal and Saibatin tribes' customs, the use of color symbols is regulated during custom Tayuhan (festivals). Custom Tayuhan was related to the places where the festival was held. For example, the red color building is a place for indigenous leaders, and the yellow place is for ordinary people. Most of Lampung tribe people like bright colors such as blue, red, yellow, white, and so on. The reason these people like the bright colors is because these colors show authority, attractiveness, glory, and loyalty. In China, one of the people's favorite colors is red; it means peace, joy, blessing, courage, prosperity, romantic, enthusiasm, and strong, but it also can be used to ward off bad luck.

In the interview, participants had no prior knowledge about how to realize that each country has its own unique historical event, historical place, or object and historical event. After learning activities, participants have knowledge to understand and realize that each country has their own unique historical object and event. Participants from Indonesia confirmed that the Mid-Autumn Festival is a traditional Chinese folk festival, and people usually enjoy this festival with their families in their hometowns. Interview result from Participant 5 (Indonesia) related to the "Season" topic:

- After watching the video, I know some of the traditional Chinese festivals are in autumn, such as the Mid-Autumn Festival. On the Mid-Autumn Festival, people enjoy the moon, eat moon cakes, play with lanterns, enjoy osmanthus flowers, drink osmanthus wine, and other folk customs. Mooncakes are the season food for the Mid-Autumn Festival. Moon cakes are round, symbolizing reunion and harmony. Mooncakes are also an important gift for friends during the Mid-Autumn Festival.

According to the results, the participants scored significantly higher on the post-test as compared to the pre-test result, $p < .005$. The result indicates there was a significant increase in the participant's historical knowledge. The result suggested that cross-cultural learning activity influenced participants' historical knowledge. The finding was consistent with Byram's assessment model, which explained historical knowledge as combining the ability to learn historical places and events, the similarities and differences across historical places, and the unique historical events (Byram, 2000).

4.3. Participants perception (RQ3)

Tables 2 and 3 include three categories to measure participants' perceptions (satisfaction, confirmation, and intention behavior using UAV).

Table 2.
Participant's perception (Satisfaction and Confirmation)

#	Category	Descriptions	Examples
1	*Satisfaction*	Are you satisfied with the decision to use UAV?	P11: I hope you can enjoy the magnificent view with the help of the UAV. I am happy to present my turn to show you the environmental places in Nanjing, China. Look around here, and you will find one of the symbols of China, the Yangtze River.
2		How do you decide to use this technology wisely?	P12: The surrounding of Nanjing Radio and Television Tower is suitable for shopping, entertainment, dining, and leisure. It is very crowded, so we cannot fly UAVs very close to

			maintaining the visitors' privacy.
3	*Confirmation*	Is using UAV to conduct cross-cultural learning meets your expectation?	P17: Using UAV, I have found many relaxing scenic spots; I would like to introduce one of them to you, called Nanjing Eye. The name Nanjing Eye is a symbol of wisdom, importance, and mystery.
4		What UAV has given to you related to the information and tools you need to learn across cultures?	P13: UAV is used to observe the detail of the location of Basket Ball playground. My partner said it is where he and his friends usually play basketball. Young men of the Lampungnese tribe love to play. These young men called "Mekhanai Lampung". Mekhanai's character aims to find the next person who can devote himself to the area where he is selected through his accomplishments and real work.

Table 3.
Participant's perception (Intention behavior using UAV)

#	Category	Questions	Examples
5	*Intention behavior using UAV*	What do you think about the benefits and difficulties of using UAVs for these learning activities?	P6: I did not pay much attention to the images taken by UAVs, but I am very happy to get new experiences that can be useful for me. This kind of system will make getting to know the outside culture easier without going there.
6		How overall thoughts, experiences, and impressions about this course in terms of using UAV for cross-cultural learning with your partner?	P17: The first use of UAV for cross-cultural learning made me feel very novel. I went to the Nanjing Eye in Nanjing and described it. Its vision is inclusive, and the picture is obvious. The image is clear when I watch other people's videos, but the cultural content is relatively easy to understand. I can understand its culture through subtitles, and some of the content matches the picture, increasing my interest in cross-cultural understanding.

5. CONCLUSION

The cross-cultural learning activities were designed in this study, and participants from China and Indonesia created authentic content about local cultural and historical objects and exchanged them with their partners. UAVs were used here to create UAV autonomous aerial videos. The study explored how UAV autonomous aerial video can support cross-cultural understanding and historical knowledge. In addition, participant perceptions of using UAV videos were explored. Our study revealed that UAV autonomous aerial video facilitated learning activities that promoted Chinese and Indonesian students' cross-cultural understanding and historical knowledge. In addition, the participants had positive perceptions of their learning experiences supported by UAV autonomous aerial video.

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Effect of a project-based learning model of technology and engineering instructional strategies on high school students' systems thinking: a quasi-experimental study

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Abstract

The cultivation of systems thinking ability is a requirement for students to adapt to social development. However, there is a lack of research related to how to cultivate students' systems thinking in technology and engineering teaching, and project-based learning theory provides a new way to cultivate students' systems thinking in technology and engineering teaching. Therefore, this study aims to design a teaching strategy for developing systems thinking based on the project-based learning model in order to investigate how it can have a significant impact on high school students' systems thinking. A total of 106 high school students were recruited for the experiment, divided into class a and class b, and 2 rounds of instructional action research were conducted. It was found that students' systems thinking was significantly improved after implementing the strategy of developing systems thinking in high school students based on project-based learning. The study has enriched the research on the teaching strategies of technology and engineering in high schools, and also developed teaching strategies and teaching cases that can be used by teachers for reference and learning in technology and engineering teaching, which have certain reference value.

Key Words: Project-based learning, systems thinking, technology and engineering, teaching strategies, quasi-experimentation

1. INTRODUCTION

The twenty-first century is known as the era of "big science", and science, technology and engineering education embodies the complex system nature of the intersection of disciplines, therefore, technology and engineering teaching and research can not be separated from the cultivation of systems thinking. problem situations, and then allows students to gradually develop students' systems thinking in the process of perceiving, understanding and exploring knowledge in the field of technology and engineering through the observation and dynamic learning process, thus helping students to form systematic knowledge construction (Godfrey et al., 2014). Therefore, the development of students' systems thinking is important for teaching and learning in technology and engineering. However, current research on technology and engineering teaching pays less attention to the cultivation of students' systems thinking ability, and the knowledge content is less concerned with the causal relationship between various parts. Therefore, in order to train students to think systemically, it is necessary to provide "scaffolding" for the cultivation of systems thinking ability, i.e., to design technology and engineering teaching strategies that aim at cultivating students' systems thinking.

2. LITERATURE REVIEW

The International Technology and Engineering Educators Association (ITEEA), the field of technology and engineering education that is the focus of this study, in its publication Standards for technological and engineering literacy: The role of technology and engineering in STEM education (Standards for technological and engineering literacy: The role of technology and engineering in STEM education), the ITEEA states that systems thinking refers to the understanding that all technologies contain interrelated components and that these technologies interact with the environment in which they operate. technologies interact with the environments in which they operate. It also includes an understanding of the generic systems model, including inputs, processes, outputs and feedback. In this paper, based on the research problem, systems thinking is defined as a thinking ability to have a clear understanding of the environment in which technology and engineering operate and the relationships between its component parts in order to propose optimal solutions.

Meyer et al. (1997) proposed a project-based strategy for teaching mathematics and conducted a study with fourth- and fifth-grade elementary school students and found that the project-based learning model helped to increase elementary school students' self-efficacy and willpower to face challenges in the process of learning mathematics and to exert effort to take action in order to overcome challenges. Gulsun (2007) investigated how project-based web-based online learning can improve students' critical thinking. A study by Dilek et al. (2011) found that teaching robotics in a project-based learning model in an elementary school science and technology course was effective in improving students' learning effectiveness and collaborative inquiry skills. Studies by Frank (2009) and Kordova (2020) have shown that project-based learning environments are conducive to enhancing students' engineering systems thinking.

However, there is less existing literature on research based on the project-based learning model from the perspective of teaching and learning technology and engineering. In addition, how to design teaching strategies based on the project-based learning model is also a research topic worth pondering. Therefore, this study focuses on teaching technology and engineering at the high school level, and with the core research question of exploring strategies for cultivating high school students' systems thinking based on project-based learning, it focuses on two fundamental questions related to the core question:

(i) How to design instructional strategies for developing systems thinking based on the project-based learning model in teaching technology and engineering in high schools?
(ii) Do instructional strategies for developing systems thinking based on the project-based learning model have a significant impact on systems thinking in high school students?

3. METHODOLOGY

3.1. Participants

This action research was carried out in a middle school in Guangxi, China, where the students have been taking general technology classes since their sophomore year of high school and have a certain level of logical thinking ability. Therefore, this study chose to randomly select two classes of sophomore students in the general technology course as the subjects of this study, in which there were 60 students in class a and 46 students in class b. The mean scores of the academic performance of the students in the two classes were basically the same. The effectiveness of applying the strategies proposed in this study was examined by comparing the differences in systems thinking between class a and class b before and after the experiment.

3.2. Instruments

3.2.1 Systems Thinking Development Effectiveness Scale

Systems Thinking Cultivation Effectiveness Scale, which includes five dimensions: system analysis ability, system synthesis ability, system implementation ability, system reflection ability and student awareness and attitude. The questionnaire is scored according to weights, with five primary indicators, eight secondary indicators, and 30 scoring points out of 100. The scale was designed based on the TEL assessment component of the NAEP Technology and Engineering Literacy Assessment Framework (NAEP, 2014). The reliability of the scale was expressed by Cronbach's coefficient, which was 0.930, indicating good reliability of the questionnaire; the KMO coefficient of the scale was 0.794, indicating good structural validity of the questionnaire.

3.2.2. Systems Thinking Development Effectiveness Pre-Test and Post-Test Papers

Pre-test and Post-test Papers: The pre-test and post-test papers of this study were designed based on the TEL assessment components of the NAEP Technology and Engineering Literacy Assessment Framework (NAEP, 2014), as well as the content of the teaching and learning, and contained multiple-choice questions and comprehensive design questions, which were designed to test the students' ability to utilize systemic thinking to solve real-world problems. It is worth 100 marks. There are three multiple-choice questions of 10 points each, totaling 30 points, which mainly test students' mastery of systems thinking. There is one integrated design question totaling 70 points, which tests students' systems thinking in designing solutions based on real-world problem situations to solve real-world problems and tasks. The question paper was tested for difficulty and time assessment after completing the design to ensure that the difficulty of the question paper was appropriate and to determine the appropriate length of time to answer the questions.

3.2.3. Design of Teaching Strategies for Cultivating Systems Thinking in High School Students Based on the Project-based Learning Model

First, this study designed the teaching objectives for cultivating systems thinking (as shown in Table 1) on the basis of research related to systems thinking and with reference to the systems thinking hierarchical model STH (Assaraf et al., 2005), the CDIO syllabus (CDIO, 2022), and the requirements of the STEL training objectives (ITEEA, 2020). Second, this study designed the instructional process for developing systems thinking by incorporating the process model of project-based learning with reference to the American Council for Engineering and Technology Education's (NCETE's) Cyclic Operational Type Process for Engineering Design Challenges. Subsequently, it then combines the goals and processes of instructional design to design instructional methods for specific instructional processes. Based on this, this study preliminarily constructed a strategic program C1 (shown in Figure 1) for fostering systems thinking among high school students based on project-based learning in a general technology course. Subsequently, the preliminarily constructed strategy C1 for cultivating high school students' systems thinking based on project-based learning was applied to the project-based teaching practice in the sophomore classroom of the general technology subject in a middle school to carry out the first round of action research. At the same time, based on classroom observation, student feedback and post-course reflection, the teaching strategies were modified and improved to form Strategy C2 of Cultivating High School Students' Systemic Thinking Based on Project-based Learning (as shown in Figure 2). The second round of action research applies Strategy C2 of Project-based Learning to Cultivate High School Students' Systems Thinking to classroom practice again and, based on classroom observation, student feedback and post-course reflection, continually improves the teaching strategy to form Strategy C3, i.e.: the final Strategy C3 of Project-based Learning to Cultivate High School Students' Systems Thinking.

Table 1
Instructional Objectives for Fostering Systems Thinking

Systems Thinking Development Objectives	*mindset*
Systems analysis capability	*Identify the roles of the various parts of the system and their interactions* *Analyze multiple factors to clarify the objectives of the activity*
System Integration Capability	*Recognizing the interaction and influence of the system with the external world* *Synthesize relevant conditions and analyze factors affecting decision-making and design*
System implementation capacity	*On the basis of the design program, consider the feasibility, safety and stability, and implement the project in an integrated manner*
Capacity for systematic reflection	*Synthesize the problems with the influencing factors and come up with constructive suggestions or effective products/programs.*

Figure 1.
Strategic Program C1 for Developing Systems Thinking in High School Students Based on Project-based Learning

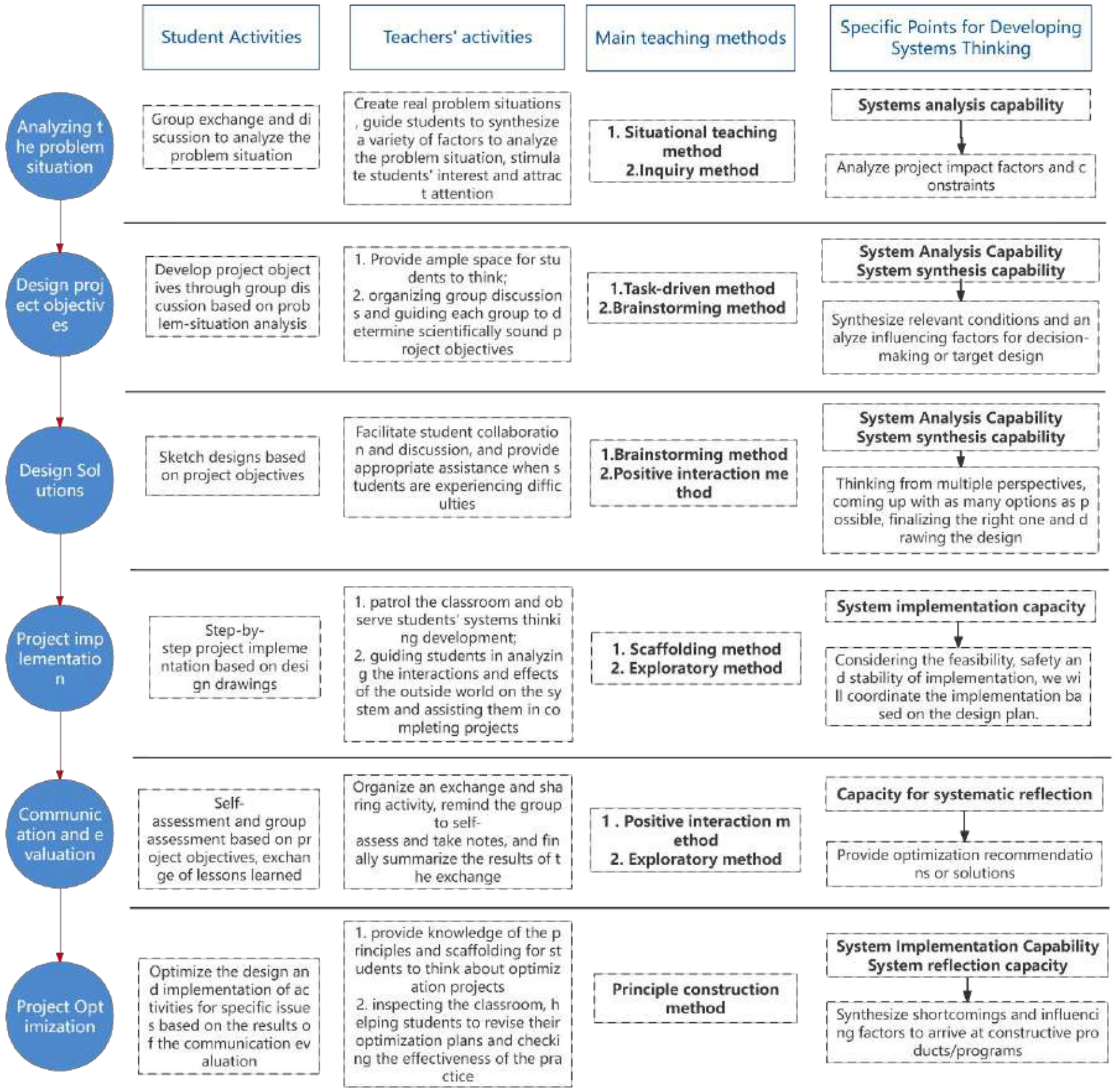
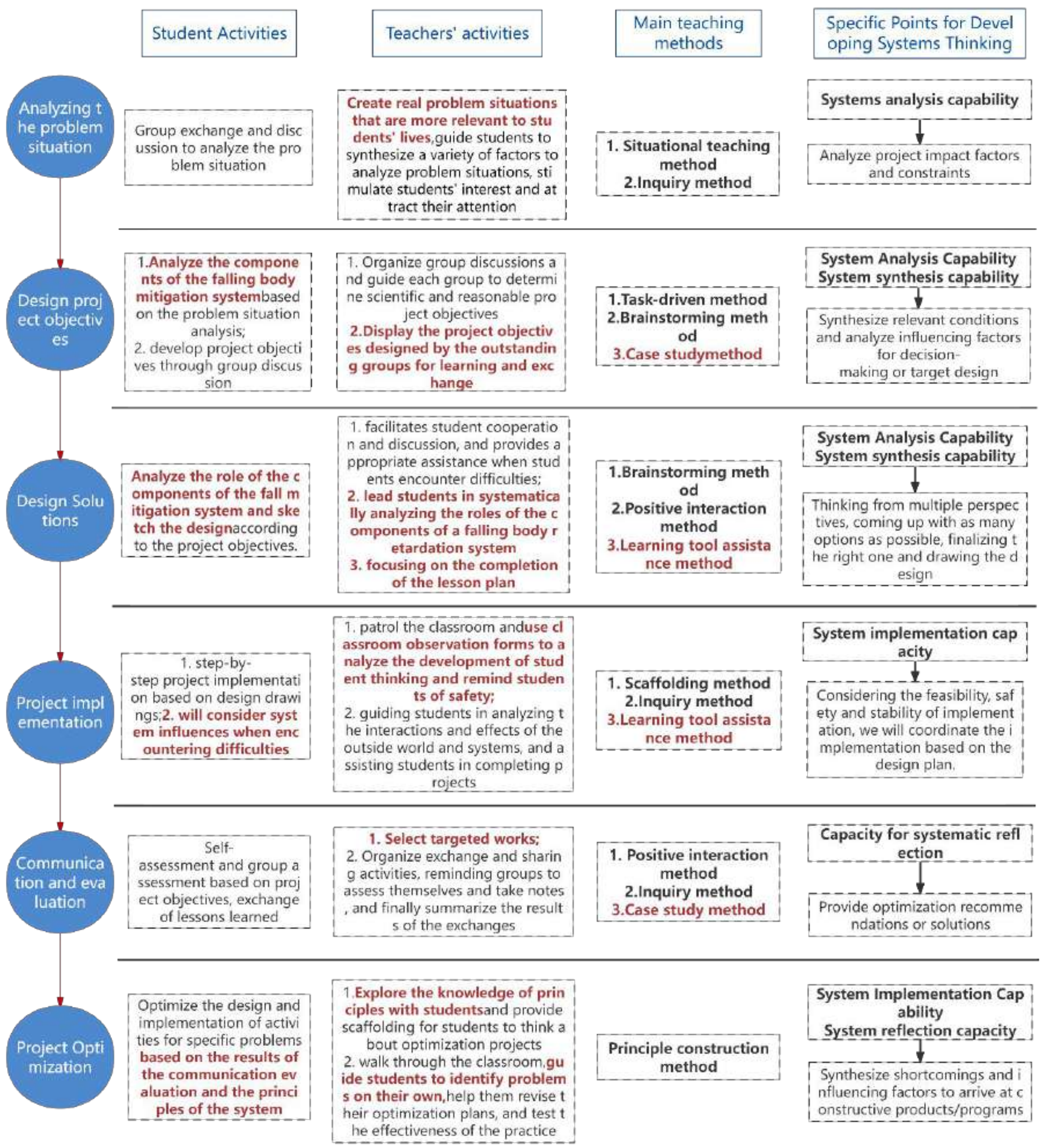


Figure 2.
Strategic Program C2 for Developing Systems Thinking in High School Students Based on Project-based Learning



3.3. Experimental design and data collection

This experiment mainly adopts two rounds of action research with experimental group control group pre- and post-test quasi-experimental research, including four segments: pre-experimental preparation, pre-experimental test, formal experiment, post-experimental test and teaching reflection. The purpose of the experiment is to investigate the application effect of the teaching strategy based on project-based learning to cultivate high school students' systems thinking designed in this study, i.e., whether the teaching strategy based on project-based learning to cultivate high school students' systems thinking is effective in enhancing high school students' systems thinking. In the formal teaching experiment, two rounds of action research were conducted by applying the teaching strategy, and test papers were distributed after each round of action research. Based on the data analysis of the pre-test paper and post-test paper on the effect of cultivating systems thinking after the teaching experiment as well as the teaching reflection, the teaching strategy was continuously modified and improved to provide reference for the subsequent related research.

4. RESULTS AND DISCUSSION

The analysis of the experimental results is mainly based on the analysis of the survey data from the questionnaires before and after the teaching experiment and the survey data from the pre- and post-tests of the test papers, to test whether the teaching strategy designed in this study based on project-based learning to cultivate systemic thinking in high school students is effective in enhancing students' systemic thinking. Among them, the questionnaire, the subjective questions of the test paper and the worksheet were mainly used to analyze the data using Excel and SPSS 26.0 statistical analysis software. The objective questions of the test paper were analyzed mainly by qualitative analysis. Due to uncontrollable factors, a total of 37 valid paired samples were recovered from the pre- and post-tests in class a, and a total of 22 valid paired samples were recovered from the pre- and post-tests in class b.

4.1. Examination of the effects of applying the C1 strategy

Paired samples t-tests were conducted on the questionnaire pre and post-test scores and the test paper pre and post-test scores of class a. The results of the analyses are shown in Tables 2 and 3. class a's systematic thinking improved by 0.906 and 2.456 in the questionnaire and the test paper, and the p-value of the paired samples test was 0.000, which is less than 0.05. It shows that there is a significant difference in the mean scores of the paired samples of the pre and post-tests of class a. The students of class a have been able to develop their systematic thinking in the questionnaire and the test paper. thinking has been developed. This indicates that the systematic thinking of the students in class a has been significantly improved after the strategy C1 of developing systematic thinking in high school students based on project-based learning.

Table 2.
Paired samples t-test for class a questionnaire

		Paired Differences							
		Mean	*St. Deviation*	*Std. Error Mean*	*95% Confidence Interval oftheDifference*		*t*	*df*	*Sig.(2-tailed)*
					Lower	*Upper*			
Class a	*Pretest Mean & Posttest Mean*	*-.905*	*.506*	*.083*	*-1.074*	*-.737*	*-10.88*	*36*	*.000*

Table 3.
Paired samples t-test for class a questionnaire

		Paired Differences							
		Mean	*St. Deviation*	*Std. Error Mean*	*95% Confidence Interval oftheDifference*		*t*	*df*	*Sig.(2-tailed)*
					Lower	*Upper*			
Class a	*Pretest Mean & Posttest Mean*	*-2.454*	*2.205*	*2.205*	*-3.159*	*-1.748*	*-7.037*	*39*	*.000*

4.2. Examination of the effects of applying the C2 strategy

Paired samples t-test was used for the questionnaire data of class b. Since the test paper data of class b did not conform to normal distribution, two correlated samples Wilcoxon test was used and the results of the analysis are shown in Tables 4 and 5.The systematic thinking of class b was improved by 0.911 and 1.994 in the questionnaire and the test paper and the p-value was 0.000, which is less than 0.05.It shows that there is a significant difference in the mean scores of the pre and post-test paired samples of class b. The systematic thinking of the students of class a was developed. This indicates that the systems thinking of the students in class b was significantly improved after the strategy C2 of developing systems thinking in high school students based on project-based learning.

Table 4.
Paired samples t-test for class a questionnaire

		Paired Differences							
		Mean	*St. Deviation*	*Std. Error Mean*	*95% Confidence Interval oftheDifference*		*t*	*df*	*Sig.(2-tailed)*
					Lower	*Upper*			
Class b	*Pretest Mean & Posttest Mean*	*-.911*	*.358*	*.076*	*-1.069*	*-.752*	*-11.93*	*21*	*.000*

Table 5.
Paired samples t-test for class a questionnaire

orderliness				
		Total N	*ordinal mean*	*Sum of Ranks*
Post-test mean - Pre-test mean	*negative rank*	*6a*	*5.00*	*30.00*

	positive rank	*16b*	*13.94*	*223.00*
	bound value	*0c*		
	total	*22*		

Remarks: a. posttest mean < pretest mean; b. posttest mean > pretest mean; c. posttest mean = pretest mean

test statisticsa

	Post-test mean - Pre-test mean
Z	*-3.133b*
Asymptotic significance (two-tailed)	*.002*

Notes: a. Wilcoxon signed rank test; b. based on negative rank.

4.3. Qualitative analysis based on questionnaires and test papers

Statistical analysis of the results of the questionnaire, the study found that: firstly, before solving problems or designing works, 91.1% of the students will search for some relevant information, 89.7% of the students will judge, compare and analyze the collected information, and 79.5% of the students will compare and analyze the existing products first. This shows that most of the students have good systematic analyzing ability, and the implementation of the teaching strategy of situational teaching method has played a positive effect. However, 74.4% of the students will calculate and analyze through mathematics in ensuring accurate design and production, compared with the choice of other questions, the percentage is still a gap, indicating that teachers still need to pay attention to cultivating students' interdisciplinary analytical ability in teaching. Second, before designing, the students who tend to carry out scientific experiments or technical exploration first, thinking that the design and production can provide the basis or support of science and technology accounted for 84.6%, which shows that the students recognize the importance of using scientific inquiry to analyze the problem situation before the formal start of the project. Thirdly, faced with some unforeseen problems in the implementation, 88.5% of the students would systematically analyze the problems and look for the causes and solutions, and 85.9% of the students would take the initiative to analyze the aspects that need to be coordinated during the implementation of the program. This shows that in the implementation of the program, in the face of some unforeseen problems in the implementation, they will look for the causes from all aspects of the program. Fourth, 89.7% of the students will objectively evaluate their own work and that of others from various aspects, and 79.5% of the students like to communicate with others through the sharing of ideas and the sharing and presentation of their work. This shows that students basically have the ability of self-evaluation and mutual evaluation. Fifthly, 91% of the students will remain optimistic and take positive countermeasures when they encounter difficulties or problems, and 80.8% of the students will persevere and devote as much energy and time as possible in order to complete a work or solve a problem. The above shows that the strategy of cultivating high school students' systematic thinking based on the project-based learning model is in line with the learning cognition of high school students, which is conducive to students' learning new knowledge and does not discourage students' student interest, and the students' awareness of and attitude towards engineering activities respond favorably.

After experiencing instructional practices, students are able to synthesize a variety of factors to analyze problem situations and develop clear and specific goals for activities on a posttest test. For example, in designing a household water supply system, Y1 students analyzed the situation and said, "Using the given water purifier, design a household water purification system so that water with different levels of filtration can be used in appropriate ways, e.g., the water that people drink needs to have a high level of filtration in order to protect their health, while water for toilets only needs to have a lower level of filtration. It is important to consider the economic, holistic and safety aspects to solve the problems caused by water pollution in the region." As another example, Y2 students analyzed "the degree of water purification, which affects the choice of water purifiers; changes in environmental water, changes in the composition of the water affects the way of design and the choice of water purifiers; the size of the instrument, which affects the location chosen for the installation; the economic cost, which affects the scalability of the plan and design."

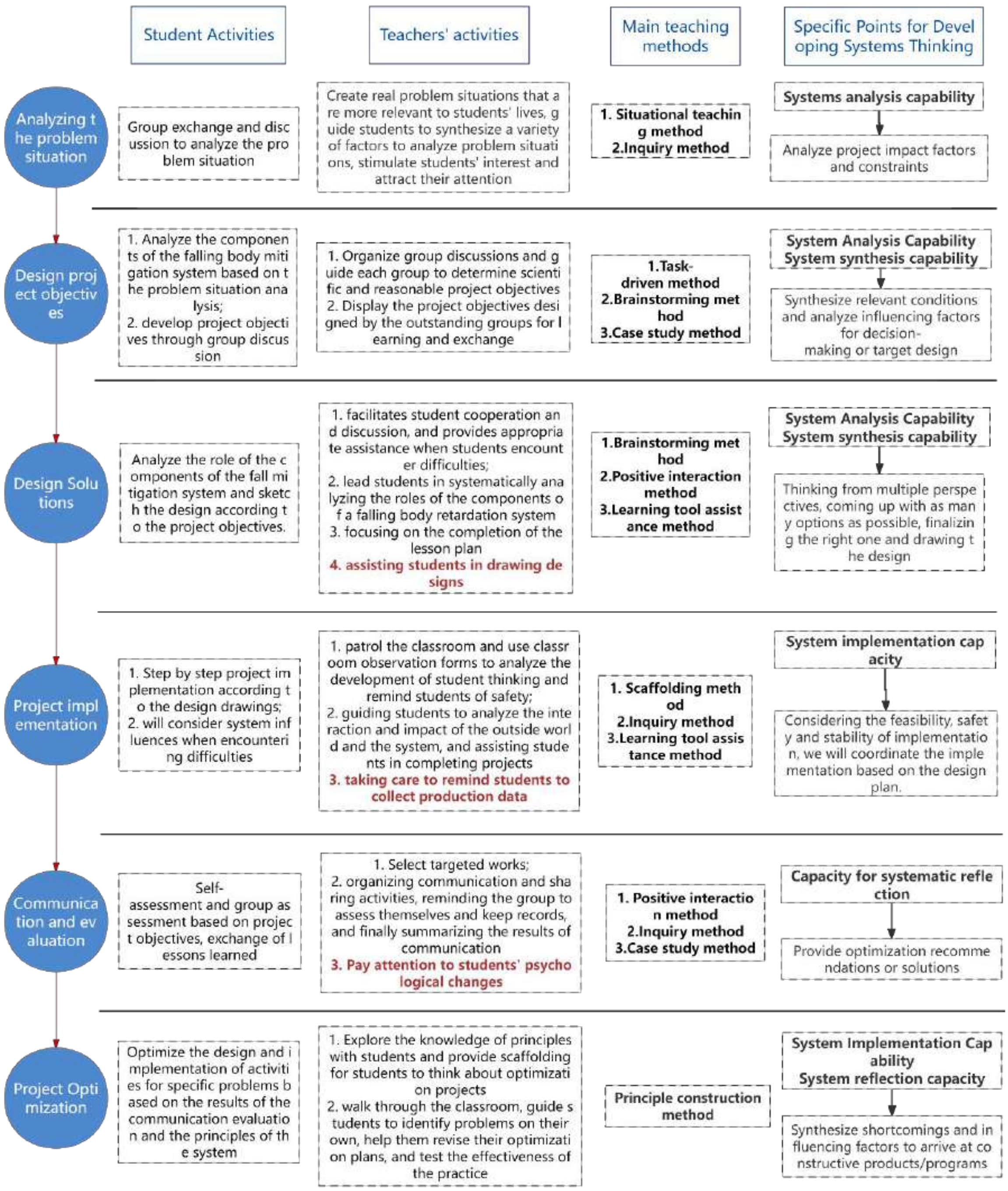
5. CONCLUSIONS AND IMPLICATIONS

5.1. Conclusion

This study constructs a strategy for cultivating systems thinking in high school students based on project-based learning. The study designed the teaching objectives of this study with the systems thinking hierarchical model STH, the requirements of the CDIO syllabus in terms of systems thinking, the requirements of the cultivation objectives of systems thinking in the high school intermediate level in STEL, and the requirements of the cultivation of engineering thinking in combination with the requirements of the core literacy in the discipline of general technology. The system thinking cultivation objectives were categorized into four dimensions, i.e., system analysis ability, system synthesis ability, system implementation ability and system reflection ability. Based on the systems thinking cultivation objectives, the process suitable for teaching and learning development was designed. Referring to the cyclic operational process model of the Engineering Design Challenge of the National Council for Engineering and Technology Education (NCETE), and combining with the process model of project-based learning, a teaching process strategy based on the development of systems thinking in high school students was designed with the goal of cultivating systems thinking in high school students as the teaching goal (as shown in the figure). This teaching process consists of 6 steps, which are analyzing the problem situation, designing the project goal, designing the solution, implementing the project, communicating and evaluating, and optimizing the project. The study applied the constructed project-based learning strategy for cultivating systems thinking in high school students to two classes in a high school in Guangxi, China, and concluded that the strategy has good results in terms of its application in teaching practice through a pre- and post-testing experimental study.

Figure 3.

Strategic Program C3 for Developing Systems Thinking in High School Students Based on Project-Based Learning



5.2. Limitations and Future Research

There are some limitations in this study during the research process, and it is hoped that further research will be carried out afterwards to supplement the existing experimental findings.

First, due to the constraints of research conditions and time, the action research in this study was only conducted in two rounds, each including six class periods, with a short teaching time, a single teaching theme, a focus on sophomore students, and a small sample size. Therefore, the experimental findings are not population generalizable. The follow-up study will expand the population scope to increase the generalizability of the experimental findings.

Secondly, the high demands placed on the research subjects resulted in fewer subjects who could ultimately participate in the experiment; therefore, the size of the experiment will be enlarged in the subsequent study to increase the accuracy and credibility of the experimental conclusions.

In addition, the study concluded through quantitative and qualitative analyses that the strategies proposed by the study can effectively cultivate high school students' systems thinking, but it lacked an analysis of the factors influencing students' systems thinking. Therefore, subsequent studies will continue to optimize the strategies of systems thinking for high school students.

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Scaffolding Design and Practice in Project-based Teaching for Engineering Literacy Enlightenment –Case Study of Project "Lightweight Heavy-Load Transport Vehicle" in Middle School Labor Course

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Abstract

Nowadays, engineering education in primary and secondary schools is in the nascent stage of its development. Many teachers have begun to incorporate engineering education into their classes, which not only enriches the original curriculum content but also promotes changes in teaching methodologies and the transformation of talent cultivation models. Middle school labor courses often use labor projects in teaching, and the practical and application-oriented content of productive labor makes it particularly amenable to integration with engineering education. With the help of scaffolding, the learning process of students will be internalized. Addressing the characteristics and demands of junior middle school education, this paper presents an iterative design and practical application of scaffolding within the project-based teaching framework, for the "lightweight heavy-load transport vehicle". It reflects on the design ideas and focuses of the scaffolding from the perspective of students' engineering literacy enlightenment, and proposes strategic suggestions for the design of scaffolding.

Key Words: Engineering literacy, Project-based teaching, Scaffolding

1. INTRODUCTION

Enlightenment in engineering literacy can open a door for children to innovation and practice, fostering their problem-solving skills, creativity, and critical thinking, enabling them to face future challenges with confidence and ease. In the enlightenment of engineering literacy, appropriate scaffolding helps students and teachers understand and facilitate the achievement of student learning objectives, especially goals like engineering literacy that are difficult to measure through traditional exams and tests, and are mainly reflected through practical projects. Labor projects are highly suitable for engineering literacy enlightenment. Emphasizing hands-on practice, labor projects allow children to experience the charm of engineering through active participation.

2. LITERATURE REVIEW

The Committee on Standards for K–12 Engineering Education describes two ways that standards in other subjects can be leveraged to boost the presence and improve the quality and consistency of K–12 engineering education in the United States, which are "infusion" and "mapping". The Committee on K–12 Engineering Education set forth three general principles for K–12 engineering education and the second is "K–12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills." The 2016 Massachusetts Science and Technology/Engineering Curriculum Framework demonstrates the essential role of language, literacy, and mathematics for science and technology/engineering learning.

3. METHODOLOGY

The "Lightweight Heavy-Load Transport Vehicle" unit is implemented within the middle school labor curriculum through project-based teaching, serving as an engineering education initiative for 7th-grade students. As a small-scale practical unit, it is positioned after the teaching and assessment of 3D modeling skills and precedes medium-sized projects.

3.1. Students' academic foundation and teaching objectives

Table 1.
Students' academic foundation and teaching objectives

Domain	*Relevant target literacy*	*Relevant attained literacy*
Engineering	*Considering while designing:* • *The general process of engineering design* • *Analysis* • *Constraints* • *Optimization and iteration*	*/*

Technology	• Multi-objective trade-offs • 3d printing (manufacturing) • Understanding the role of lightweighting in sustainable development	• Computer modeling
Math	• Calculating linear functions and piecewise functions	• Performing basic calculations of decimals and negative numbers, and the use of calculators
Science	• Utilizing experimental methods and analysis • Understanding factors affecting structural strength	• Using spring scales and electronic scales
Language and literacy	• Writing simple expository texts using terminology • Expressing opinions with a clear center, basis, and organization	• Reading expository texts • Reading across media • Gathering information using the internet and other media

The definition of "multi-objective trade-offs" involves using an algorithm to allocate weights and balance weighted factors in multi-objective problems, in order to find a solution that aims to optimize multiple objectives under given constraints. "Multi-objective trade-offs" are not only inevitable issues that engineers encounter in engineering projects, but also common challenges in other work domains and in solving complex real-world problems in daily life.

3.2. The theme and the driving question

The theme consists of design objectives. Initially, the theme was "load-carrying vehicle" with the objective of "load capacity." Later, considering multi-objective trade-offs, sustainable development, and the complexity of real-world problems that include both interrelated and unrelated goals, as well as those that are positively correlated, the theme evolved to "lightweight heavy-load transport vehicle." The three design objectives are "lightweight," "mobility," and "load capacity." The corresponding key driving question is: How can you design a vehicle that integrates lightweight performance, load capacity, and mobility?

3.3. The design approaches

Table 2.
The design approach for scaffolding and corresponding teaching methods

Phase	Intent	Optimizations made to the previous phase
I	• Guiding students in design and production	N/A
II	• Helping students understand learning objectives	• Discarding the step-by-step modeling video • Adding rubrics, a 3D printing manual, and flowcharts and structural diagrams
III	• Assisting students in establishing a metacognitive system	• Adding a "Self-Diagnostic Manual" • Re-editing the flowchart

Table 3.
The design approach for literacy in related domains

Domain	Phase I	Phase II	Phase III
Engineering	• Mentioning a few engineering concepts	• Enhancing the engineering concept of design process • Understanding engineers' work	• Integrating engineering literacy, e.g., iteration and optimization, multi-objective trade-offs, into student activities • Comprehending design cycle
Technology	• Project-specific 3D modeling and 3D printing	• General-purpose 3D modeling and 3D printing	• Same as in phase II
Math	N/A	• Presenting linear functions and piecewise functions	• Prompting students to use linear functions and piecewise functions
Science	• Experimental methods • Using spring scales	• Same as in phase I • Using electronic scales	• Same as in phase II • Using standard weights
Language and literacy	N/A	• Speaking using terminology	• Writing using terminology • Encouraging verbal communication and persuasion

3.4. Iterating of scaffoldings

3.4.1. Phase I: Guiding students in design and production

(i) Content

Initially, teaching and learning relies on a set of the following scaffolds:

- slides: explaining vehicle structure and dimensions
- a dimension table: specifying the measurement of each component
- an instructional video: explaining the vehicle modeling steps progressively
- an evaluation scale: including evaluation items, specific indicators, assessment criteria, and scoring

(ii) Autonomous learning ability

A limited number of explorable questions were opened to students, e.g., What are the key dimensions that need to be set to ensure the smooth movement of the vehicle?

(iii) Engineering literacy

The following engineering concepts are involved, e.g., structural optimization, design process, testing, kinematic pair, and connection methods.

(iv) Language skills and literacy

Few are involved.

3.4.2. Phase II: Helping students understand learning objective

(i) Content

The most important scaffolding introduced in this phase is a rubric that designates students with virtual engineering titles, with three levels: "Senior Engineer," " Intermediate Engineer," and "Junior Engineer."

Table 4.
Rubric: Dimension control

Phase	*Intent*	*Optimizations made to the previous phase*
I	• *Guiding students in design and production*	*N/A*
II	• *Helping students understand learning objectives*	• *Discarding the step-by-step modeling video* • *Adding rubrics, a 3D printing manual, and flowcharts and structural diagrams*
III	• *Assisting students in establishing a metacognitive system*	• *Adding a "Self-Diagnostic Manual"* • *Re-editing the flowchart*

The following scaffoldings have been added:

- a 3D printing operation manual: universal in nature, not limited to this project alone
- a flowchart: illustrating the workflow of this project
- a structural diagram: showing the system structure of the cart's construction
- examples of common failure cases: displaying failure modes such as cracks and fractures

One scaffolding has been removed:

The step-by-step modeling video

(ii) Autonomous learning ability

The rubric, in contrast to the evaluation scale, focus on process assessment rather than outcome assessment, fostering students' self-evaluation skills and aiding in the comprehension of learning objectives. By eliminating the step-by-step modeling video, which serves as an overly direct and explicit "standard answer," students gain increased freedom to explore.

(iii) Engineering literacy

By utilizing rubrics, students can develop their understanding of the work of engineers. Through flowcharts and structural diagrams, students can grasp the general process of engineering design by understanding procedures and systems.

(iv) Language skills and literacy

Students are encouraged to use technical terms in oral communication.

3.4.3. Phase III: Assisting students in establishing a metacognitive system

(i) Content

The most significant change in this phase compared to the previous one is the addition of a "Self-Diagnostic Manual."

Table 5.
The general structure of the self-diagnostic manual

Module	*Key points*	*Intention*
Completion	• *Including project completion and submission completion*	• *Metacognitive system: process monitoring*
Known conditions/constraints/initial settings	• *Using quantitative indicators as much as possible* • *Encourage reasonable questioning*	• *Metacognitive system: clarity monitoring and accuracy monitoring*
Experiment/functionality testing/performance testing	• *Involving multi-objective trade-offs* • *Including operational methods, standards, experimental results, and ideas for improvement* • *Mainly based on objective indicators*	• *Metacognitive system: clarity monitoring and accuracy monitoring*

The Completion Module explains what tasks students need to accomplish during the process and what kind of archives or objects need to be submitted at the end. It is located at the very beginning of the manual. It is concisely designed, covering only two pages.

The Known Conditions/Constraints/Initial Settings module takes the form of a dimensional specification table in this project, providing both constraints and a start for iteration. Students can only begin the first round of design with this module. Taking this project as an example, the ideal scenario is that even if the structures students initially design are simple cuboids and cylinders that are very easy for middle school students to construct, after several rounds of iteration, a result that better meets the target can emerge. Under the table, special prompts encouraging students to communicate with teachers about constraints and ideas are gradually added.

The Experiment/Function Testing/Performance Testing module essentially corresponds to the optimization and iteration part of the engineering design process. Experiments and tests are the basis for optimization and iteration, and optimization and iteration are the purpose of experiments and tests. In short, this module completes the optimization and iteration of engineering design solutions through the implementation of experiments and tests. In the supporting teaching materials, the view that 'complex real-world problems always involve multi-objective trade-offs' is clearly put forward, strengthening the concepts of 'optimization' and 'iteration'. The design of the module content also reflects these two points.

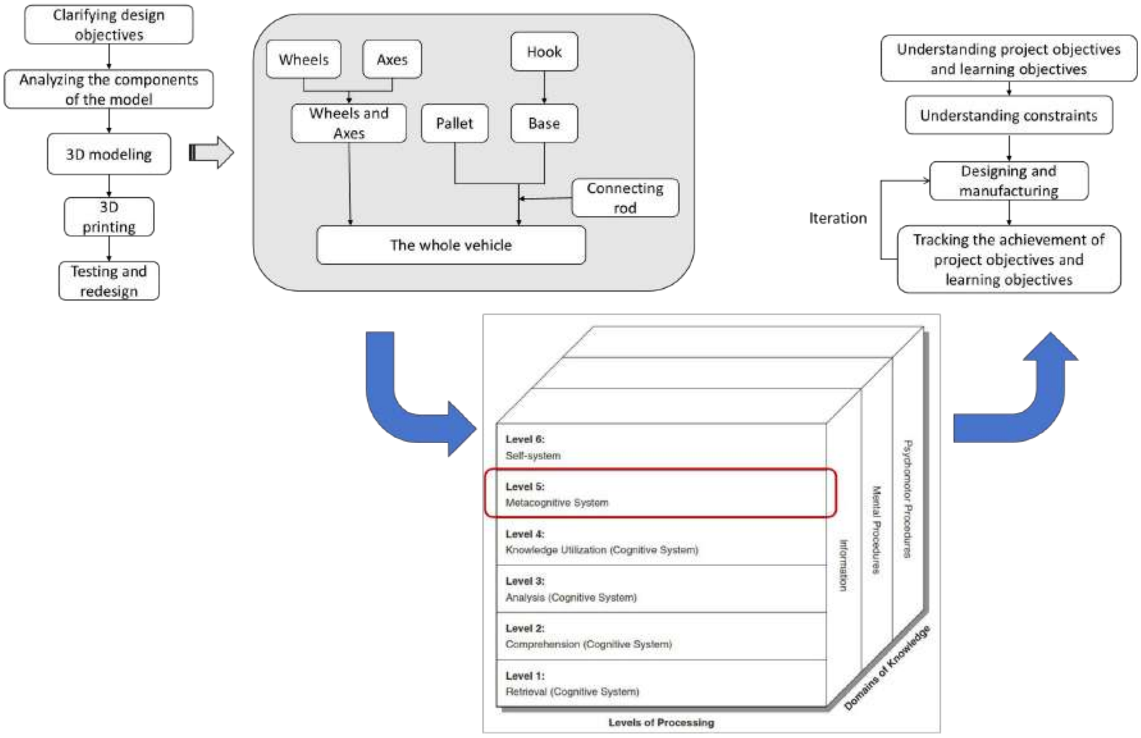
Table 6.
The structure of Experiment/Function Testing/Performance Testing module

Activity	*Cycle I*	*Cycle II*	…
Goal I	*Experiments and tests*	*Experiments and tests*	…
Goal II	*Experiments and tests*	*Experiments and tests*	…
…	…	…	…
Trade-offs	*Analyzing and discussing*	*Analyzing and discussing*	…

One scaffolding is adjusted:

Flowchart: Revising the flowchart to align with the 'Self-Diagnosis Manual', emphasizing the concepts of 'design loop' and 'iteration'.

Figure 1.
Flowchart revised in phase III



(ii) Autonomous learning ability

By using the 'Self-Diagnosis Manual', students are able to monitor their learning process, clarity, and accuracy. Understanding objectives and tracking the achievement of objectives support student-led learning. Students comprehend that because design requires iteration and optimization, engineering design is not linear but cyclical.

(iii) Engineering literacy

Core engineering competencies are integrated into student activities. Iteration and optimization, multi-objective trade-offs are challenges that students address. Students start to understand that engineering design is not linear but cyclical.

(iv) Language skills and literacy

On the basis of the previous phase, students are asked to imitate the teacher's use of terminology in writing within the 'Self-Diagnosis Manual'. This requires that students have a complete understanding of the terminology used by the teacher as a prerequisite.

4. RESULTS

4.1. Autonomous learning

Autonomous learning refers to the ability of students to independently set learning goals, select learning strategies, monitor the learning process, and reflect on both the process and outcomes. At the onset of a project, students may be more accustomed to being guided rather than autonomously gathering information from various media forms. Teachers review the "Self-Diagnosis Manual" to identify issues that students have not fully expressed and communicate with students accordingly. They provide indices, suggesting that students seek answers at specific locations within the materials. It is recommended that students adopt a learning strategy of first reading the outline to understand the organizational framework of the materials, fostering a learning habit akin to "looking up in a dictionary," which allows them to search for the likely locations of answers to their questions within the outline. As the project progresses, changes in data are observed.

Table 7.
Autonomous learning results

Percentage	*Early stage of the project*	*Later stage of the project*	*Difference*
• *Questioning issues that have been clarified in the materials*	*36.5*	*21.7*	*-14.8*
• *Not questioning without carefully reading the materials and monitoring the learning process*	*43.2*	*23.2*	*-20.0*
• *Not questioning but carefully reading the materials and monitoring the*	*8.1*	*40.6*	*32.5*

learning process			
• *Asking constructive questions*	*12.2*	*14.5*	*2.3*

It can be observed from the table that there are significant changes in the proportions of the first three types of students.

4.2. Language and literacy

At the beginning and end of the project, students' abilities in reading and writing expository texts in the 'Self-Diagnosis Manual' are assessed.

Table 8.
Reading and writing expository texts results

Percentage	*Early stage of the project*	*Later stage of the project*	*Difference*
• *Producing expository text writing at a level that matches or exceeds the quality of the texts provided by the teacher*	*6.3*	*8.9*	*2.6*
• *Producing text writing at a level that is nearly on par with the texts provided by the teacher, with occasional inaccuracies*	*21.3*	*45.6*	*24.3*
• *Producing text writing that shows a gap compared to the texts provided by the teacher, with occasional inaccuracies and conceptual errors*	*52.5*	*38*	*-14.5*
• *Producing confusing text writing, characterized by numerous inaccuracies and frequent conceptual misunderstandings*	*2.0*	*7.6*	*-12.4*

The data reveals notable change in the percentages of the latter three categories of students.

4.3. Engineering literacy

As a brief project, it is designed such that students complete at least one iteration, which entails going through two cycles of design. This allows students to grasp the concept of design iteration within the shortest possible timeframe.

In the actual operation of the project, some students completed two or more iterations due to various reasons. Some students, due to high efficiency, completed more rounds of iteration within the same period of time. Some students, interested in the project theme, applied to extend the project into a longer one. Others faced the challenge of changing 3D printers during the project; after overcoming the shortcoming of the printer's printing speed, the time students spent waiting for their prints with the new 3D printer was approximately half of that with the old one, shortening the development cycle. Some students voluntarily spent time outside of class to design a cart that satisfied themselves. There is an overlap among these four types of students.

Table 9.
Reasons why some students could complete two or more iterations

Percentage	*In all students*
• *High efficiency*	*17.7*
• *Rational approaches for four tests*	*5.1*
• *Choosing new equipment*	*16.5*
• *Spending time after class*	*15.2*
• *Total number of students who completed two or more iterations*	*22.8*

During each round of iteration, the rationality of the optimization approaches led by students is assessed.

Table 10.
Optimization approaches results for five tests

Percentage	*In all students*
• *Rational approaches for five tests*	*22.5*
• *Rational approaches for four tests*	*31.3*
• *Rational approaches for three tests*	*26.3*
• *Rational approaches for two tests*	*13.8*
• *Rational approaches for one test*	*2.5*
• *Rational approaches for zero test*	*3.8*

Table 11.
Optimization approaches results for five tests of students who have conducted two or more iterations

Percentage	*In students who have conducted two or more rounds of iteration*
• *Rational approaches for five tests*	*44.4*
• *Rational approaches for four tests*	*54.6*
• *Rational approaches for three tests*	*0*
• *Rational approaches for two tests*	*0*
• *Rational approaches for one test*	*0*

• *Rational approaches for zero test*	*0*

5. DISCUSSION

The scaffolding and teaching strategies adopted in the project facilitate the development of students' learning strategies and the monitoring of the learning process, help students improve their ability to read and write expository texts.

The project's duration is well-matched with the setup for one iteration. To encourage students to engage in more iterations, scaffolding and teaching strategies for time management should be re-designed, and duration should be extended with the addition of new equipment. Teachers need to review the "Self-Diagnosis Manual" on-site during class and communicate with students to track each student's optimization process, which is essentially tracking each student's learning.

Students who go through more rounds of iteration tend to develop more rational optimization strategies. The reason is that they have accumulated practical experience in the two design cycles and have preliminarily developed the literacy for optimization and iteration. Immediately applying newly acquired concepts, skills, and thinking habits into the next design cycle helps students to consolidate and internalize them.

The more iterations a student goes through, the more their optimization strategies tend to become rational. The reason is that they have accumulated practical experience in two design cycles and have preliminarily developed the literacy for optimization and iteration. Immediately applying newly acquired concepts, skills, and thinking habits into the next design cycle helps students to consolidate and internalize them.

Considering the need to cultivate students' engineering literacy, we recommend that optimization and iteration should go through at least two rounds, instead of the one round in this project, so that both teachers and students can significantly identify the students' progress.

The most frequently used scaffolding throughout the entire project is the Self-Diagnosis Manual. Many of the observations and data mentioned earlier come from it. At the cognitive system level, it effectively helps students to extract, understand, analyze, and apply relevant project knowledge. At the metacognitive system level, it assists both students and teachers in monitoring the learning process, clarity, and accuracy. Teachers can review the Self-Diagnosis Manual during class, after class, and during research to identify issues and potential, and adjust teaching strategies and project settings.

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Space re-engineering: The construction of "Information Science and Technology Innovation Center" focusing on the development of technology and engineering literacy

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Abstract

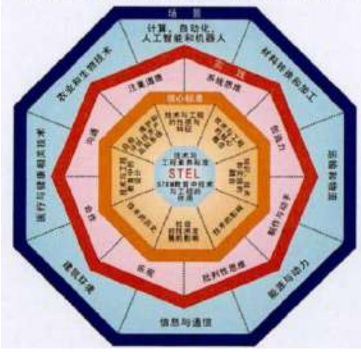
Technology and engineering education is an important way to improve the national scientific and technological literacy, to speed up the national construction. In the primary and secondary school stages, we cultivate students' innovative thinking, practical ability and teamwork spirit, based on various technologies and engineering practices, the positive link and free switching combination of technical engineering scenarios. This study will focus on space re-engineering as a carrier, with open, diverse and complex functions, to meet the needs of various forms of learning, as the key of space re-engineering, so as to meet the environmental needs of community learning, make technology and engineering learning really happen, and promote the improvement of students' core competence.

Key Words: space re-engineering, technology and engineering literacy

1. ORIGIN：THE CONSTRUCTION BACKGROUND OF INFORMATION SCIENCE AND TECHNOLOGY INNOVATION CENTER

For STEM education, learning space is a basic place for students to conduct STEM learning. In the early stage of STEM's promotion of regionalization, we are fully aware of the importance of space construction for project promotion and student practice, whether it is the attempt for the whole class of students or the community practice for some students.

图1 技术与工程素养标准内容的八角形模型



Through studying “ technology and engineering literacy standard ” , which upgraded in July 2020, technology and engineering as an important field of STEM education, it is also provides students with very clear standards of how to become with technology and engineering literacy of the future citizens, and through the model figure in the core standards, technology and engineering practice, engineering scene positive link, free rotation combination provides support for students literacy, this is also for us, as a STEM education seed school, to seek new growth points and breakthroughs in action, namely: rethinking the learning space. As a new starting point, the learning space should have the following characteristics:

1.1. It can meet the environmental needs of community learning.

Space and the scene setting function is not only students can learn in the real situation and solve problem, another value is that students can learn in the open environment (such as: classroom, studio, library, computer classroom, compound, open space, try in different areas of the table, equipment configuration) to form a research community, through cooperative learning, resource sharing, iterative reflection, to optimize and improve the learning ability.

1.2. It can make technology and engineering learning really happen.

The space and scene setting based on technology and engineering should be able to help students to open independent learning, team cooperation, communication and practice based on a certain problem situation, and the organic combination of core goals, projects and practice will naturally promote the real occurrence of students' technology and engineering learning and practice activities.

1.3. It can support the improvement of core competencies.

Space construction and scene setting mean that each project with the taste of technology and engineering will be formed. Students will gradually enrich their core abilities such as "system thinking", "innovation", "manufacturing and production", "critical thinking", "collaborative isomorphism" and so on core competence and literacy by different projects in different grades.

Based on the above thinking, we firmly take this step, hoping to leverage the design and implementation of technology and engineering projects through the construction of technology and engineering space and scenes that meet the above characteristics, so as to truly enable students to learn.

2. CONSTRCTION: THE CONSTRUCTION ACTION OF INFORMATION SCIENCE AND TECHNOLOGY INNOVATION CENTER

The design and construction of Information Science and Technology Innovation Center is an attempt of future learning space, and also the transformation of traditional classrooms. Open diversity, composite functions, to meet the needs of various forms of learning has become the key words in the construction. Different campuses of our school have chose different technical and engineering scenarios to try it out. Take East Campus as an example, the " Information Science and Technology Innovation Center" in this campus focuses on the planning and construction of computing, automation, artificial intelligence, robot, and material transformation and processing.

2.1. Positioning: functional space for blurring subject boundaries.

The information science and technology innovation center is composed of experience perception area, learning practice area and display and sharing area, which integrates five different functional classrooms such as artificial intelligence, UAV competition and 3D laser printing. Support students to start independent research in the functional environment, and at the same time, present the design process，engineering thinking and learning results of students from class or club, so as to realize interdisciplinary learning and cooperation in a subtle way, and improve the ability of design and production, technology and engineering.

2.1.1. Experience perception area：

Knowledge is the beginning of action. In order to enable students to have a better understanding of front-edge technology and engineering development in a real, intuitive and systematic environment, areas such as smart furniture interactive experience, smart logistics, 5G + AR interactive experience have been set up in this area, Model the devices in the real environment, link the people to the virtual world,, help students truly experience the induction control, voice control, remote control technology on the basis of the technology and engineering history. So as to help students more intuitively understand of artificial intelligence model corresponding to the real case, and understand what happened between the simple model and the real case.

2.1.2.Learning and practice area: 5 functional classrooms of technology and engineering.

Area 1: STEM dedicated classroom. The technology and engineering classroom that can accommodate the whole class, includes folding projection, electronic screen, erasable and absorbable writing board, replaceable work display area, combining long table, movable notebook, woodworking machine tool and corresponding tools, etc. The whole classroom is an open space integrating design, information collection, creative design, hands-on practice, systematic thinking presentation and work presentation. Teachers encourage each child to explore, think and do hands-on practice. Keep technology and engineering learning going in a systematic and coherent scenario, making it possible for students to learn and work like an engineer.

Area 2: EV3 Robot Classroom. In order to facilitate students learn from the basic structure construction, mechanical transmission, gradually advanced to logic programming, sensor learning application. Robot classroom in the design of the community and the whole class students for artificial intelligence entry-level learning needs, try to use combining tables and chairs, computer and programming software, sensors, Lego, etc., to help students to build simple models in systematic learning , through the model of learning practice to further expand innovation and creation, according to the actual demand such as "scratch" "micro:" bit "," intelligent control board "" Internet "" robot " module, to sow the seeds of hope for the subsequent higher entry of technology and engineering learning into the robot arena.

Area 3: Artificial intelligence competition room. The artificial intelligence arena uses gray and white as the main color, and uses light and shadow to create an atmosphere of technology and progress. The combination of aluminum square pass, gypsum board, customized light soft film material, with simple and environmentally friendly materials combined to create a different immersive learning atmosphere. There are two customized competitions in the space to meet the needs of the mainstream competition venues. On one side of the arena, a maintenance and debugging area is equipped with common tools to provide hardware support for equipment debugging, maintenance and charging. On the other side is the viewing rest area, with the storage function. The white writing board on the wall is used as a tactical discussion area for children to arrange troops, organize ideas and conduct tactical discussion.

Area 4: UAV classroom. The classroom is equipped with a special drone collision network, the first view screen, with lights to create a tense competitive atmosphere. Based on community activities, on the basis of learning the concept, type, use and flight principle of UAV, students will conduct take-off, fixed orbit flight, and obstacle flight in the room.

Area 5: Youth science and technology innovation camp. The layout of the wall leaves out more display space, and all the tables and chairs are also lightweight and movable. Through the business school operation mode, let the community students through the company, with their own efforts to find the real needs of specific people in real life, and with STEM concept for product (or model) to design, product creatively, to truly meet the needs of people, and through the form of the product conference, students have a new understanding of the profession of designer and engineer.

2.1.3.Display and sharing area:
It provides more interactive areas for teachers and students to display and share. Most of the content is replaceable, which is convenient for teachers and students to adjust the display contents at any time according to their learning needs.

2.2. Stringing: meet the learning needs of different communities.

After the initial creation of the relevant technology and engineering scene space, school strives to restructure the school-based curriculum and extension curriculum, forming different technology and engineering projects that can meet the needs of the whole class and the community to learn, and by reflecting on the practical experience of different learning communities, the promotion experience is accumulated.

Scope of application	Choice space	Course and project sources	Learning objectives and requirements
Large class groups	1. Visual presentation of technical and engineering operation processes and safety tips in the space; 2. A comprehensive space integrating equipment, tools, learning, practice and display, which is convenient for teachers to cooperate and guide	1. Introduce basic version and advanced version of the course resource package and consumables suitable for large class; 2. Basic equipment of engineering and technology: small woodworking machine tools, tools, etc.	Each group relies on the same course material (small project), condenses the team wisdom to form innovative design, and can learn and use technology to make works or products;
A community study group	1. An integrated area of experience perception, learning practice (learning in 1 or 2 Spaces), display and sharing; 2. With combined, movable tables and chairs and operating equipment, tools, and erasable and absorbable writing boards;	1. School-based design and development of personalized technology and engineering projects that meet the needs of some students; 2. Customize related tools and consumables;	Depending on the community project, each group can make use of the circulation experience, learning and practice in different areas. The team focuses on computational thinking and building technology, designs and produces works or products in response to real problems, and carries out practical testing and optimization of technology and engineering in the scene.

2.3. Surfacing: gradually increase the number of engineering and technology courses.

At present, the school has formed some basic projects and high-quality community projects, such as: basic projects of "sound transmission", "DIY sealing machine", "revealing telescope", "lazy bubble machine", etc., advanced version of the project such as: "smart campus security", "smart campus logistics manager" , etc.; community projects like UAV, EV3 robot, "artificial intelligence speech recognition", "intelligent rescue early warning", "intelligent community vehicle management", etc., all these attempts provide us experience to gradually develop more projects based on other technology and engineering scenarios.

3. REFLECTION ON THE PRACTICE OF INFORMATION SCIENCE AND TECHNOLOGY INNOVATION CENTER

3.1. A new upgrade to the technical and engineering space scene.

On the basis of the original, hope to try to connect with science laboratories, labor micro farms and other spaces to recreate space scenes related to agriculture, biotechnology, energy and power, so as to provide new perspectives and opportunities for the expansion of courses and the improvement of students' technical and engineering abilities.

3.2. Soft power enhancement.

The landing of space and curriculum (or project) urgently needs to improve teachers' ability of guidance and evaluation. Use the third party's project-based training, school's internal research and training to continuously hatch more guiding forces.

3.3. Tracking evaluation of students' technical and engineering ability.

Evaluation is to make a better start. How to track and evaluate students' technology and engineering is not only the accumulation of students' learning process, but also the monitoring of individual and team learning. Therefore, the design of evaluation standards and methods will also become the thinking point for practice promotion in the next stage.

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Providing STEM Learning Experiences to Young Children: Chinese Kindergarten Teachers' Practices and Reflections

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Abstract

This qualitative study explored how STEM learning experiences were provided to young children aged three to six years old in kindergartens of China. Kindergarten teachers' written examples of STEM activities together with their reflection notes on their roles when providing those activities were collected (N = 70). Originations of the activities, types of the activities, locations of the activities, and teachers' instructional strategies were analyzed and compared across different age groups. The results indicated that kindergarten teachers provided a wide range of STEM activities to young children. Project-based construction activities were the most common STEM activities. More than half of the STEM activities were introduced by teachers based on curriculum plan or perceived interests of the children. Teachers adopted different instructional strategies to children of different age groups with a focus on individual work for younger children and a focus on group work for older children. Teachers' perceived roles when providing those STEM activities were also analyzed. Different levels of teacher mediation in early STEM learning experiences were discussed. Implications and suggestions for future research were proposed.

Key Words: Kindergartens, STEM practice, Instructional strategies, Teacher mediation

1. INTRODUCTION

As science and technologies are applied in all sectors and all aspects of human society, everyone needs to be prepared with values, knowledge and skills that required to live and work with technologies. Therefore, K-12 Science, Technology, Engineering, and Mathematics (STEM) education has become the priority for the educational reform of countries around the world to make their citizens to adapt to social practices (National Institute of Education Sciences [China], 2017). Over the last decade great importance has been attached to STEM education in early childhood settings (e.g. Haden et al., 2014; Kallery & Psillos, 2002; Kazakoff, Sullivan, & Bers, 2013; Moomaw & Davis, 2010). Educators and researchers believed that involvement in STEM activities at a young age can lead to children's foundational STEM ability and dispositions (Moomaw, 2013; Nadelson et al., 2013), and that early science and mathematics learning experiences are beneficial for developing foundational knowledge and thinking skills (Katz, 2010). Researchers also stressed that early childhood is a critical time when children form their own STEM identity and professional interests (Brunsell, 2012; Bybee, 2013; Campbell, Speldewinde, Howitt, & MacDonald, 2018).

1.1. China's Context of Early Childhood STEM Education

According to China STEM Education White Paper (thereafter called White Paper), STEM education in China, though at initial development stage with national curriculum frameworks or standards yet to come, has been actively and continuously explored culturally appropriate and practical approaches rather than imitating the imported ideas from the western countries (National Institute of Education Sciences [China], 2017). The White Paper also revealed current challenges for China's STEM education. For example, there is a need of an overarching design connecting curriculum contents and learning objectives through primary school to high school in a progressive manner. Besides, there are different understandings of STEM education, and curriculum standards and evaluation mechanism have yet to establish, the implementations of STEM education across the country also varied a lot (National Institute of Education Sciences [China], 2017).

Early childhood educators in China were introduced to STEM education in most recent years, since a number of international conferences, professional development programs and expositions on STEM education were held in the eastern coastal region of China, for example, Jiangsu Province (Tao, 2019). In July 2016, Seminar on Experiment Project of National K-12 Technology and Engineering Curriculum and International Technology and Engineering Educators Association (ITEEA) Chinese Center Launch Ceremony was held in Nanjing, Jiangsu, China. This was the first time that kindergarten was officially included in the national initiative of advocating STEM education. In September 2018, at the Annual Conference of STEM Education in Jiangsu Province, the Guidelines for K-12 STEM Curriculum in Jiangsu Province (Trial Version) (thereafter called Guidelines) developed by Jiangsu Collaborative and Innovative Research Center on STEM Education was announced. The rationale underpinning the Guidelines including fostering each child's STEM literacy, encouraging project-based learning, and creating a flexible and inclusive learning environment. At the kindergarten level, the Guidelines put an emphasis on young children's play-based learning and hands-on learning during STEM activities (Jiangsu Collaborative and Innovative Research Center on STEM Education, 2018).

In China, kindergarten refers to childcare centers for children aged three-to-six-year old. In kindergarten children are generally grouped into three age levels, namely 3-4-year-old level, 4-5-year-old level, and 5-6-year-old level (Tao, 2019). According to the national Guidelines for Kindergarten Education (Trial Version) (Ministry of Education [China], 2001), there are five learning domains, including language, health, social and emotional development, art, and science (with mathematics included). Currently, learning expectations and educational advices related to technology and engineering learning is not included in the national framework (Tao, 2019; Yang, Wu, & Li, 2021). With regard to science and mathematics education in kindergarten, a number of studies suggested that Chinese teachers, following the cultural tradition of collectivism, tended to use direct and whole-class instruction, and children were more likely to participate in teacher-led and topic-related activities (Hammer & He, 2016; Li, Chi, DeBey, & Baroody, 2015; Rao, Ng, & Pearson, 2010).

1.2. Kindergarten Teachers' Practices and Perceptions of Early STEM Education

A number of previous studies on early childhood teachers' intentions to implement STEM education indicated that they were hesitate to incorporate STEM education into their classrooms due to various reasons, including teachers' misconceptions of STEM education (Brenneman, 2011), low self-efficacy (Counsell et al., 2016; Greenfield et al., 2009), and insufficient educational preparation or professional training (Pendergast, Lieberman-Betz, & Vail, 2017). Recent studies also revealed early childhood teachers' complex reaction to STEM education (Wan, Jiang, & Zhang, 2020). They could perceive the value of STEM education for young children, but reported they were not ready or confident to teach STEM content (Tao, 2019; DeJarnette, 2018; Hammack & Ivey, 2017; Linder, Emerson, Heffron, Shevlin, & Vest, 2016; Saçkes, 2014). In a few studies, preschool teachers reported various practical constrains of instructional time and resources, administrative support, and challenges to cater for children's diverse developmental levels during the process of STEM implementation (Jamil, Linder, & Stegelin, 2018; John, Sibuma, Wunnava, Anggoro, & Dubosarsky, 2018; Park, Dimitrov, & Park, 2017).

A most recent review of empirical studies on STEM education in early childhood indicated that the idea of implementing STEM education was relatively new in the early childhood context, and we had limited knowledge about the actual practice of STEM in early childhood classroom (Wan et al., 2020). Among the few studies exploring how STEM education was enacted in kindergarten classrooms, Tank et al. (2018) examined teacher and children interactions during engineering design-based STEM activities in a US kindergarten. They suggested that engineering design could be a good way to facilitate STEM integration, and teacher played an important role in scaffolding children's talk and action. Tippett and Milford (2017) explored how two Canadian pre-kindergarten teachers incorporated STEM activities in their classrooms. The study showed that young children were engaged in hands-on and project-based activities such as designing and building birdhouses. Campbell et al. (2018) examined Australian preschool teachers' practices of STEM education. They found that STEM was presented in a wide range of forms, and teachers' practices were related to "their own understanding of what STEM actually means and their level of comfort in developing this further. (p. 23)"

1.3. Significance

Although a number of studies have helped to describe the current situation of STEM education in early childhood context, little is known about the actual practice of STEM in kindergarten classrooms. Studies on what and how early STEM learning experiences are provided to kindergarten children are also limited. The study is significant because it attempts to explore Chinese kindergarten teachers' practices and reflections of providing early STEM learning experience to young children, and it provides us with valuable insight into ways of realizing STEM education in the EC context.

1.4. Purpose and Research Questions

Given the gaps in the literature identified in the previous section, the aims of the current qualitative study were: 1) to reveal STEM activities kindergarten teachers provided to young children of different age groups; 2) to explore teachers' instructional strategies when providing STEM activities to young children, and 3) to explore teachers' perceived roles when providing STEM activities to young children. The research questions were:

(i) What STEM activities did kindergarten teachers provide to young children?
(ii) What were the teachers' instructional strategies when providing STEM activities to young children?
(iii) What were the teachers' perceived roles when providing STEM activities to young children?

2. METHOD

2.1. Data Collection

In July 2023, Professional Learning Community for Kindergarten STEM Education was established in Guangdong Province. Kindergarten teachers from Shenzhen and Zhuhai participated in a semester-long professional development program. Teachers were invited to submit written examples of STEM teaching and learning activities showcasing their best practices in developing lessons, activities, and providing STEM learning opportunities at the end of the program. Till late February 2024, seventy examples of STEM activities were received from 86 teachers coming from 27 kindergartens all over the province. A complete written example of STEM activity included a detailed description of the process of the activity, and the teacher's reflections on his/her roles when providing such a STEM learning activity to young children.

Among all the seventy examples of STEM activities received from kindergarten teachers, seven examples were received from the teachers of 3-4-year-olds, accounting for 10% of the total number. Around one third of the examples were from the teachers of 4-5-year-olds, and more than half of the examples were from the teachers of 5-6-year-olds. The number of STEM activities examples received from different age groups are presented in Table 1.

Table 1.
Number of STEM Activities across Different Age Groups

	Age Groups			
	3-4-year-olds	4-5-year-olds	5-6-year-olds	Total
Number of Activities	7 (10%)	23 (33%)	40 (57%)	70

2.2. Data Analysis

The qualitative data generated by teachers' written examples of STEM activities were analyzed in three stages. In the first stage, STEM activities were grouped into age levels, namely 3-4 year-old level, 4-5-year-old level, and 5-6-year-old level. Each written example of activity was examined and analyzed to ascertain the origination of the activity, the type of the activity, and the location of the activity. The number and percentage of activities falling to each category were the tabulated and compared across age groups. In the second stage, each written example of activity was considered more holistically to determine the teachers' typical instructional strategies. Activities organized with similar instructional strategies were clustered into categories. The number and percentage of activities falling to each type of instructional strategy were then tabulated and compared across age groups. In the third stage, teachers' reflections on their roles in those STEM activities were examined and analyzed. Excerpts from teachers' notes were selected for inclusion if they were representative of a certain role.

3. FINDINGS

The findings are presented in three sections that address the research questions. The first section presents general description of the STEM activities provided to children of different age groups through comparing the originations of the activities, types of the activities, and locations of the activities. The second section presents findings about teachers' instructional strategies when providing those activities to young children. The third section presents finding about teachers' reflections on their roles when providing those activities to young children.

3.1. Origination, Types, and Locations of STEM Activities by Age Groups

3.1.1. originations of the activities

In those written examples of STEM activities, teachers explained where the ideas of those activities came from, that is whether the ideas were introduced by teachers based on the curriculum plan or their perceived interests of the children, or the ideas were initiated by a group of children who shared a particular interest. For example, the teachers mentioned,

> "Recently, we've been learning light and shadow. So, I think making a sundial would be a great activity for the children (Miss Shen, a teacher of 5-6-year-olds)".
>
> "Children in my class were fascinated about the shapes of cookies and how cookies are made from. So I decided to make cookies with children together" (Miss Xu, a teacher of 3-4-year-olds).
>
> "After our field trip to the nearby fire station, a group of children were eager to make a real-life size fire truck in the classroom" (Miss Zhou, a teacher of 5-6-year-old groups).

As Table 2 displays, STEM activities introduced by teachers were common among all age groups, accounting for 63% of the total number. By contrast, STEM activities initiated by children were found in the older age groups, accounting for 37% of the total number. This finding indicated that the older children tended to demonstrate more autonomy and agency in the STEM activities.

Table 2.
Originations of the STEM Activities by Age Groups

Origination of the activities	3-4-year-olds (N = 7)	4-5-year-olds (N = 23)	5-6-year-olds (N = 40)	Total (N = 70)
Introduced by teachers	7	14	23	44 (63%)
Initiated by children	0	9	17	26 (37%)

3.1.2. types of the activities

According to the teachers' descriptions and explanations of the learning objectives, the activity steps, the materials and tools children used, and the duration of the activities, those STEM activities can be broadly categorized into six types, namely, science experiments, growing plants or keeping animals, project-based construction, quick hands-on making, cooking activities, and sand and water play. Project-based construction activities refer to children's building, constructing, or making things through the steps of designing, collecting materials, making, and improving, which often lasts for several weeks or several months. By contrast, quick hands-on making activities refer to children's assembling or making things according to the design, instructions, and simple tools provided by teacher during the whole-group time.

Table 3.
Types of STEM Activities by Age Groups

Types of STEM activities	3-4-year-olds (N = 7)	4-5-year-olds (N = 23)	5-6-year-olds (N = 40)	Total (N = 70)
Project-based construction	3	13	25	41 (59%)
Quick hands-on making	2	4	7	13 (18%)
Growing plants/keeping animals	0	1	4	5 (7%)
Cooking activities	1	3	0	4 (6%)
Sand, mud, water play	1	0	3	4 (6%)
Science experiments	0	2	1	3 (4%)

As Table 3 shows, more than 50% of the activities fell into the category of project-based construction, indicating that this type of activities were the most common STEM activities provided to young children. Quick hands-on making activities were also popular, accounting for 18% of all the activities. Other types of STEM activities such as conducting science experiments, growing plants or keeping animals, cooking activities, and sand and water play only took up small percentages. These findings indicated that kindergarten teachers were more likely to associate STEM activities with project work and hands-on activities.

3.1.3. locations of the activities

In teachers' descriptions of the STEM activities, they also mentioned where the activities were conducted either from their written words or from the photos of activity processes. In summary, STEM activities were conducted in the following locations: indoor, indoor plus outdoor, and outdoor only. 'Indoor' refers to those activities conducted within and throughout the classroom, including the science area, STEM center, creative art area, block area, and pretend play area. 'Indoor plus outdoor' refers to the locations of the STEM activities switch between the classroom and the outdoor space. 'Outdoor only' refers to those activities conducted in the outdoor space only, for example, the sand and water play activities. As Table 4 shows, 60% of the STEM activities were conducted within the classrooms. About a third of the activities were conducted with the combination of indoor and outdoor settings. Very few activities were conducted in the outdoor space only.

Table 4.
Locations of STEM Activities by Age Groups

Locations of STEM activities	3-4-year-olds (N = 7)	4-5-year-olds (N = 23)	5-6-year-olds (N = 40)	Total (N = 70)
Indoor	4	17	21	42 (60%)
Indoor + Outdoor	3	5	17	25 (36%)
Outdoor	0	1	2	3 (4%)

3.2. Teachers' Instructional Strategies

Based on teachers' descriptions of the processes of the activities and their interaction with the children, three types of instructional strategies were identified, namely, whole-class instruction followed by individual work, whole-class instruction followed by group work, and group work with informal instruction. Table 5 provides a brief description to each type of instructional strategies with the activity summary. Table 6 presents the numbers of STEM activities falling to each type of instruction strategies.

Table 5.
Types of Instructional Strategies with Descriptions and Activity Summaries

Type of Instructional Strategies	Description	Activity Summary
Whole-class instruction followed by individual work	• identifying the topic • engaging children in whole-class discussion on the topic • providing common background knowledge and experience • preparing materials and resources • letting the children work individually on designing, making and testing • observing each child's performance and providing individualized guidance and help to children who had difficulty accomplishing the task	Making Bubble Wands (3-4-year olds) 1. Teacher drew upon children's interests and prior experience of playing with bubble wands. 2. Teacher displayed various kinds of bubble wands by pictures and videos. 3. Teacher introduced the topic by asking children how to make bubble wands with pipe cleaners. 4. Teachers encouraged children to draw and paint the bubble wands they would like to play with. 5. Children individually drew their bubble wands, explored the pipe cleaners provided by the teacher, and made their own bubble wands by bending, cutting, and taping the pipe cleaners. 6. The teacher walked around and provided guidance and technical support to children who had difficulty using scissors and tapes. 7. Children played with their bubble wands in the outdoor space.
Whole-class instruction followed by group work	• identifying the topic • engaging children in whole-class discussion on the topic • providing common background knowledge and experience • letting the children work in groups on designing, collecting materials, making and testing • facilitating the children's communication and cooperation • observing and documenting the progress of each group • providing guidance and support to each group • organizing group presentations and encouraging each group to present their ideas and products in front of the class	Costume Show (5-6-year olds) 1. Children were preparing for a costume show on their graduation ceremony. The teacher and children agreed upon with the idea of making their own costumes. 2. The teacher asked children to think about what they might need to make costumes and encouraged children to discuss with their parents and collect materials and tools from home. 3. The teacher took children to visit a tailor's shop in the community. The tailor gave children a brief introduction of fabrics, patterns, and stitching techniques, as well as basic steps of making clothing. 4. The teacher encouraged each child to have a trial cut on small pieces of paper to see whether children could make costume models. 5. When children succeeded in making costume models with paper, children are divided into several groups (cloth, newspaper, plastic bags), and started group work on designing the pattern, measuring, cutting, and hand sewing. 6. Children's costume show by group, followed by whole-class discussion on what problems they had during the process and how they solve those problems.
Group work with informal instruction	• following a group of children's particular interest and helping the children to clarify their goal • collecting materials and tools with the children • providing sufficient time and space for children's exploration • facilitating the children's communication and cooperation	Making a Washing Machine Model (4-5-year olds) 1. In the pretend play area, several children talked about that they need a washing machine for their laundry. 2. The teacher encouraged children to think about what kind of washing machine they would like to make, and what materials they might need. The teacher encouraged children to draw their ideas on a piece of paper. 3. The teacher encouraged the children to present their

	• observing and documenting children's actions and conversations • providing support and guidance only when children asking for help	drawings and ideas to each other and let them vote whose idea was the best. 4. Children decided to make a front-loading washing machine. The teacher took the children to the resource room of the kindergarten. 5. Children picked up some cardboard boxes, a small metal cookie box, some colored masking tapes, and some double faced adhesive tapes. The teacher set aside a space in the classroom for the children's work. 6. Children worked together on measuring, cutting, taping and assembling. Teacher provided technical support during the process.

As Table 5 displays, different from the third type of instructional strategy, the first two types of instructional strategies required careful planning and preparation by the teacher. For example, the teachers spent a great deal of time providing initial experiences with the topic for children to build background knowledge and become familiar with what they were going to investigate. However, the teachers using the third type of strategy let the children take the lead, and provided sufficient time, space, materials and resources for the children to do their own research. They spent time observing and listening to children carefully while providing minimal assistance.

As Table 6 shows, more than half of the activities fell in the type of whole-class instruction followed by group work, indicating that it was the most common strategy used by kindergarten teachers. About a quarter of the activities fell in the type of whole-class instruction followed by individual work, and one fifth of the activities fell in the type of group work with informal instruction. It was noticeable that children of the older ages were more likely to be engaged in group work than those 3-4-year-olds.

Table 6.
Types of Instructional Strategies in STEM Activities by Age Groups

Types of Instructional Strategies	3-4-year-olds (N = 7)	4-5-year-olds (N = 23)	5-6-year-olds (N = 40)	Total (N = 70)
Whole-class instruction followed by individual work	7	6	6	19 (27%)
Whole-class instruction followed by group work	0	15	22	37 (53%)
Group work with informal instruction	0	2	12	14 (20%)

In summary, the above two sections present the actual picture of how early STEM learning experiences were provided to young children in Chinese kindergartens. Findings revealed that kindergarten teachers organized various types of STEM activities in different settings, and used different types of instructional strategies. One noticeable trend was that the youngest children were more likely to be engaged in teacher-introduced activities in the form of whole-class instruction followed by individual work, and children of the older ages were more likely to be engaged in children-initiated activities in the form of group work.

3.3. Teachers' Reflections on Their Roles

At the end of their written examples of STEM activities, kindergarten teachers' were also invited to reflect on the roles they played during those activities. According to teachers' descriptions and the keywords they used, their perceived roles were broadly clustered into the following three categories.

3.3.1. teacher as guider

Almost all the teachers of 3-4-year-olds saw themselves as guider. They set clear goals in mind for children's development and learning, made careful planning and preparation, and provided individualized guidance to accommodate children's different developmental levels and education needs. These teachers recalled that they had to provide a great deal of input on the activities because they found that the youngest children "didn't seem to have a clear purpose of their action", "they had a short attention span and couldn't focus on the task for long periods of time", "they preferred to focus more on their own work rather than those of others". Teachers also mentioned that they had to cater for children's diverse needs during the activities. Therefore, STEM learning experiences were less likely to occur without the teachers' intentional planning, preparation and guidance. For example, one of the teacher wrote:

> "Proving STEM learning activities to the 3-4-year-olds was an adventure for me. It took me a lot of time to think about an appropriate topic that originated with the children's interest and experience……I made a detailed activity plan, prepared different kinds of materials, and I guided them to explore, manipulate and

compare those materials repeatedly" (Miss Li, a teacher of 3-4-year-olds).

For the 3-4-year-olds, some had very limited fine motor skills, some had very limited experience of using tools, and others were confused designing with imagination. Since children's current level of development varied so much, I decided to provide individualized guidance to each child" (Miss Chen, a teacher of 3-4-year-olds).

3.3.2. teacher as observer and facilitator

Most teachers of 4-5-year-olds and 5-6-year-olds tended to view themselves as observer and facilitator. The teachers observed children's actions and listen carefully to children's conversations, thoughts and comments, and who identified the areas of children's particular interest, helped with gathering resources, invited experts to come to the classroom, who facilitated children's interaction and cooperation during their group work. For example, the teachers wrote:

"Compared with 3-4-year-old children, 4-5-year-old children have more experience in identifying problems and solving problems. They love fun and exploratory play, and their enthusiasm for participating in activities has been greatly improved. I encourage children to discover problems, conduct experiment, and look for answers by themselves rather than telling them directly" (Ms Yang, a teacher of 4-5-year-olds).

"I provided technical support and assistance when children had difficulties, and stepped back as an observer when children continued their inquiry" (Mr. Zhang, a teacher of 4-5-year-olds).

"I made close and careful observations on children's activities to identify whether they had any troubles or found something new, so I could give timely support" (Mr. Xu, a teacher of 5-6-year-olds).

3.3.3. teacher as learner

A small number of teachers of 5-6-year-olds tended to view themselves as leaners. The teacher expressed their own curiosity and enthusiasm to the children's investigation. When encountering new concepts and ideas, the teacher and the children worked together as a team by looking for information together, collecting materials together and solving problems together. For example, one of the teachers wrote:

"I've learned to trust my children and conduct investigation right along with them. I started to review my conventional practice from the lens of STEM education, and I found as a teacher I don't have be afraid of or be shameful of my limited content knowledge, because we and the children were all members of the community of STEM learning" (Ms Zhou, a teacher of 5-6-year-olds).

"I was surprised by how my children were deeply engaged in the project. They were actively drawing upon their prior experiences and trying out different solutions when encountering problems…….During the entire project, I learned to slow down and spent time listening to them and working with them. I believe that children are active learners, and so am I" (Ms Ding, a teacher of 5-6-year-olds).

4. DISCUSSION

4.1. Ways of Realizing STEM Education in Early Childhood Context

In contrast to previous studies revealing that preschool teachers worried about the appropriateness of STEM education in the EC context (Park et al., 2017) , and hesitated to implement STEM lessons with their young children (DeJarnette, 2018), the present study showed that the Chinese kindergarten teachers provided a wide range of STEM activities to young children aged 3-6-year old, indicating the possible ways of realizing STEM education in early childhood context. First, the study found that more than half of the STEM activities were introduced by teachers based on the curriculum plan or their perceived interests of the children. This finding indicated that the kindergarten teachers actively looked for STEM learning opportunities embedded in the curriculum or theme activities, and actively capitalized on children's interests, experiences, and prior knowledge. These teachers made thoughtful plans of the activities with learning objectives in mind, they carefully selected materials for children to explore, and incorporate science, mathematics, engineering, and technology into the children' investigations and explorations. According to Moomaw (2013), one of the effective teaching practices that are critical to early STEM learning is intentional teaching, which means that "teachers are purposeful in all aspects of teaching. They plan the curriculum and environment with specific outcomes and children in mind. They remain alert for teachable moments as they occur throughout the classroom" (2013, p. 5).

Second, the study revealed that the kindergarten teachers engaged young children in the following six types of activities, namely, science experiments, growing plants or keeping animals, project-based construction, quick hands-on making, cooking activities, and sand and water play. This finding indicated that STEM could be found everywhere in the EC context. When reviewing the seventy examples of STEM activities received from kindergarten teachers, we found that children learned to use various tools for observation, measurement and experimentation in science center; began to understand the life cycle of plants (e.g. tomatoes and cucumbers) and became involved in extensive, in-depth investigations when taking care of the plants and animals over time; engaged in measuring, pouring, mixing, stirring, baking and boiling in cooking activities; spent days working together to build castles and tunnels with water, sand, and mud; learned about various adhering materials such as glue, tape, staples, twine, and even nails when building with cardboard boxes, wood or bamboo plates. Among those six types of activities, project-based construction activities were the most common STEM activities, indicating that project approach was an effective way to realize STEM education in the EC context. According to Katz (2010), project work provides opportunities for young children to conduct an extended in-depth investigation of a particular topic, thus beneficial for developing children's intellectual capacities, deepening their knowledge and understanding, fostering skills and dispositions, and promoting positive feelings.

Third, the study found that the majority of the STEM activities were conducted within the classrooms, for instances, in the science area, STEM center, creative art area, block area, and pretend play area, however, very few STEM activities were conducted in the outdoor space only. This finding contrasted with the previous study on Australian preschool teachers' STEM practice, indicating the teacher's preference of having STEM activities in the outdoor settings because they believed that outdoor spaces embraced more opportunities for learning about the environment (Campbell et al., 2018). According to Moomaw (2013), outdoor settings may offer rich STEM learning potential, for example, young children can "explore plants, animals, and natural phenomena that are not available in the classroom" , and "use their whole bodies to explore materials, which helps them understand the physical properties of objects in new ways" (p. 115).

4.2. Level of Teacher Mediation in STEM Activities

Another important finding drawn from the qualitative data was that the kindergarten teachers adopted different types of instructional strategies with different levels of teacher mediation to children of different age groups. Almost all the STEM activities of the youngest children and a small number of activities of the elder children fell in the type of whole-class instruction followed by individual work. This type of instructional strategy requires a high level of teacher mediation since the teacher had to select and identify an appropriate topic, make a detailed activity plan, provide common background knowledge and experience, prepare for the materials for children to manipulate, observe, compare and explore, and provide individualized guidance during children's individual work to accommodate their different developmental levels and education needs. The teachers of the youngest children perceived their role as guiders, creating conditions for young children to interact with the common materials and tools in the classrooms, introducing "relevant and meaningful information required for the child to understand their inquiry", and "giving a more direct and higher level of support for the child's conceptual development" (Lewis, Fleer, & Hammer, 2019, p. 10).

More than half of the STEM activities of the elder children fell in the type of whole-class instruction followed by group work. This type of instructional strategy requires a medium level of teacher mediation since the teacher's work mainly focused on organizing whole-group discussion on the topic, providing common background knowledge and experience, and supporting children group work on designing, collecting materials, making and testing. Compared with the whole-class instruction followed by individual work, this type of instructional strategy gave children more freedom and autonomy on choosing the materials and peers they would like to interact with. A few STEM activities of the oldest children fell in the type of group work with informal instruction. This type of instructional strategy requires a low level of teacher mediation since the teacher's work mainly focusing on following a group of children's particular interest, providing sufficient time and space for children's exploration, observing and documenting children's actions and conversations, and providing support and guidance only when necessary.

A noticeable trend was found that when children gain more confidence and competence of their exploration with the increase of their age, the level of teacher mediation in STEM activities gradually decrease, and the teachers gradually gave children more autonomy during the STEM activities. Along with the adjusting the level of mediation in STEM activities, we also found that teachers adjusted their role in the activities, from the guider who took care of children's every step of the activity, to the observer and facilitator who provide support to children's interaction with peers, to the learner who worked with children as a learning community and got deep appreciation and understanding of children's actions and behaviors.

5. IMPLICATIONS AND CONCLUSIONS

This study provides important implications for early childhood educators. First, STEM learning experiences in the kindergarten can take various forms and can occur anywhere, within the classroom or in the outdoor space. Whether introduced by teachers based on curriculum plan or the perceived interests of the children, or initiated by a group of children who share particular interest, kindergarten teachers can actively create conditions for young children's investigations and explorations. Second, instead of implementing an entire new STEM curriculum, kindergarten teachers can capitalize on young children's interest, experiences and knowledge, thus engaging them in a variety of STEM activities with materials and tools that were common and available in the kindergarten. As Nayfeld et al. (2011) suggested "teachers will be able to provide effective learning experience for children both by recognizing and extending children's spontaneous scientific play (p. 985)." Third, the role of the teacher in supporting young children's STEM learning is important. From the 'guider' of the 3-4-year olds to the 'observer and facilitator' of the 4-5-year olds, and to the 'learner' of the 5-6-year olds, kindergarten teachers may use different levels of mediation to accommodate young children's developmental levels and education needs.

This qualitative study provided a snapshot about how early STEM learning experiences were provided to young children. Findings revealed that kindergarten teachers organized various types of STEM activities in different settings, and used different types of instructional strategies. One noticeable trend was that the youngest children were more likely to be engaged in teacher-introduced learning activities in the form of whole-class instruction followed by individual work, and children of the older ages were more likely to be engaged in children-initiated activities in the form of group work.

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EXPERIENCES IN PEDAGOGY OF DESIGN: Design based Design brief concept learning through Technasium design project assignments

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ABSTRACT

This pilot study investigates the way that young students of a Dutch Science Technology Engineering and Mathematics (STEM) secondary school subject Research and Design (R&D) reason about making the Design brief requirements during a design project assignment. The core of the Dutch Technasium school course R&D curriculum is to involve students in real-life design problems (or real-life research questions) with a problem owner at a company or organization. In teams, students explore the nature of the design problem and establish a Design brief. Possible solutions are examined, and one option is being worked out into a design, a prototype or a product depending on the level of complexity. Despite a growing interest in technology education, little research has been executed to ascertain how secondary school students' reason about the way that a Design brief is created and the purpose of the Design brief in general. Such research is important because it provides a view on students' knowledge about the concept and reasoning about the relationship between structure and function, a fundamental in nearly every form of scientific reasoning. Combining a theoretical substantiation about defining a Design brief and surveys among students; pre-knowledge, and formulations of requirements among students of R&D were sampled during their very first design project.

Starting secondary school student designers have almost no Design brief pre-knowledge. Therefore, concepts are personal and to various to summarize. Students are thinking from the position of product user (in order of importance) first in Design brief terms that are picturing their ambition about a product/artefact to design, then of the structures that will give them the desired functions of product/artefact to design and as last about functions of product/artefact to design.

Key Words: STEM, Stichting Technasium (ST), subject Research and Design (R&D), Design brief, The Design brief requirements, Learning through design, Pedagogy of Design, Structure-function reasoning, Design assignment, Project based learning, design based learning.

1. DUTCH INNOVATIVE STEM COURSE

STEM is a curriculum based on the idea of interdisciplinary educating students in four specific disciplines in an applied approach. STEM integrates disciplines into a cohesive learning based on real-world applications. (Hom E.J. 2014). The Dutch course Research and Design (R&D) aims to do just that, different disciplines from natural sciences get integrated into technological research and design projects through real life problems.

1.1. Distinctive success of high school course Research & Design

After just fifteen years of existence a new secondary school course is broadly accepted and recognized in the Netherlands. The Technasium education "formula" has proven to be very successful and is showing a growth from five schools to ninety-five in the period from 2006 to 2017 (Vaksectie Natuur & Techniek SLO, 2017). Students can follow the course from their first year to the final exams. R&D is compulsory in lower secondary education and elective in upper secondary education. The subject features project-based learning through which students learn important skills, like: Cooperation, Entrepreneurship, Creativity, Communication, Self-management and Project-based work. A major goal (Schalk& Bruning, 2014) is to get acquainted with different technical professions and to give students a better view on the world of science and engineering. Therefore, students get acquainted with different professions and issues in science at early age. This helps them to make an informed decision when choosing their future studies (Blume-Bos, van der Veen, 2015).

This unique approach connects companies and institutions of all sizes to secondary schools and support learning engineering through research and design. The final assignment "Meesterproef" also involves Polytechnic or University experts as a support during the project (Stichting Technasium 2020). The companies that own problems are not necessarily involved in engineering but do need engineering support. Most of the companies appreciate unforeseen innovations suggested by R&D students, "a fresh angle", and invest their time in student technological education & literacy, as they are possible future students and employees. Therefore, throughout their secondary school career R&D students supported by field experts and coached by teachers work on authentic tasks originating from companies and various institutions. The company or institution provides these tasks in consultation with a teacher through project assignment descriptions. Project assignments are ought to be written on the level of educated adult professionals asked to solve the problem and are therefore not being adjusted to students' age or skills level. These projects assignments are first written by the teacher (in consultation with the companies, assignment field experts and/or institutions) but later in their R&D career the students will go out to find problem-owners themselves and write their own projects in consultation with the company or institution.

2. CONCEPT LEARNING

Technasium students always work in a cooperative team on real life and current science and technical projects. As there are no textbooks for this subject, for each project a unique assignment is written, together with the client, which is then used instead of the text course book. While working on an assignment during seven to ten weeks the main learning objective of the course R&D is learning about a technological profession and developing different skills and competences. However, when students of Technasium are working in teams on design challenges they are actually learning through experience during a collaborative learning process in a real-world context. Inquiry on project-based learning confirms (Bell, 2010) that important contemporary skills like: critical thinking, creativity, collaboration and communication are being learned. Students are also asked to reflect on their learning weekly in short personal reports. During execution process of research or design assignment, concept learning is a very important aspect of the R&D subject. There are several possible approaches for learning concepts in R&D:

- Confronting student ideas; The meaning technological concepts have in students' minds directly affect their learning in technology because these concepts form a framework from which to construct other concepts and base actions on (Jones, 1997). It is therefore important to respond to the pre-existing student ideas.
- Concept-context learning; One of the main goals of concept-context learning is to answer the question: why am I learning this? (Kortland, Mooldijk & Poorthuis, 2017) Something R&D does by giving real life problems as context. Science education research and experiences in the classroom by science teachers throughout history show that, when used correctly, analogies can make abstract concepts more meaningful to students, making hard to visualize concepts more accessible (Glynn, 2007)
- Using informal learning characteristics; Students do not only learn in the formal place of education. A lot of learning takes place outside the school, through social interactions, (side)jobs, cultural influences, etc. Scott D Johnson (1997) argues that formal learning can benefit from the implementation of informal characteristics. Context learning, peer-based learning, activity based learning or reflective practice are good examples of informal learning.
- Learning by design: LBD or learning by design is a project-based approach. It combines two different pedagogical approaches, namely problem-based learning and case-based reasoning. Solutions to new, real life, problems are found by adapting existing knowledge and already known solutions (Breukelen, de Vries & Schure, 2016). The learning by design approach uses real-life design problems. This problem is solved through two cycles of activities. One cycle for design and one cycle for investigation which are related to each other (Kolodner, 2002). Designing leads to questions, which brings up a need to know about lacking information, design skills, etc. The student then goes to investigate this need to know to be able to implement it back into the design. Investigating can lead to new questions in which case the investigation cycle starts once more.

The way in which this approach stimulates concept learning is by learning from experience. The problems used in learning by design should deliberately evoke the conflict in the students' views so that the existing knowledge is not sufficient for solving the problem, thus making it necessary to go into the investigation cycle and develop new ideas (Breukelen, de Vries & Schure, 2016).

- Thinking aloud; Getting students to explain their thoughts gives them more insight in their own thinking process. In the thinking aloud method the focus is on the student, not on the teacher or the textbook, or what is right or wrong (Kortland, Mooldijk & Poorthuis, 2017).
- Visualisation; Another way to approach the learning of concepts is by visualization. The forms depend on the type of concept you want to teach or the learning goal you have in mind. Animations can visualise concepts throughout space (movement) and time. In concept cartoons students views about concepts are visualised along with the scientifically "correct" idea. Students are then invited to join in on the discussion the cartoon characters are having about the different ideas (Kabapinar, 2005). Another way of visualising concepts can be done through concept experiments. Seeing is not always believing and it is thus useful to use an approach such as predict, observe, explain to make sure that the visualisation has the effect of visualising new knowledge (Kortland, Mooldijk & Poorthuis, 2017).
- Responsive teaching: In responsive teaching the teacher takes a "back seat" observing the students instead of directing, and teaching based on the observations (Hong & Diamond, 2012). The students get an assignment or initiate an activity on their own after which the teacher takes on an observing role. The teacher can then join the activity as a peer, asking questions about the observations, provoking discussion and using the observation to link to new knowledge. The students learn first by experiencing themselves and then exchanging their experiences and knowledge. Responsive teaching can then use the knowledge gained from observing and asking questions to teach the desired knowledge by linking them to what the students experienced themselves.

3. LEARNING BY DESIGN

A project-based approach; learning by design (LBD) uses real life design problems. Designing brings up questions, inquiry on lacking knowledge. Gained knowledge will be then used for designing. Need to know and need to do alternate and are inseparably connected to each other by the design process. (Kolodner, 2002). There are few good reasons to choose design as a learning context such as: collaborative learning process, contextual learning and reflective learning (D.H.J. van Breukelen 2017).

3.1. Learning concepts by design

Although learning to design or by designing is not even one of the learning goals of the course R&D, as students are learning through projects based on the design process they come in touch and get acquainted with concepts

and terms of design and designing. The learning by design approach stimulates concept learning by learning from experience. The problems used in learning by design, certainly in Technasium widely undefined projects, deliberately provide the conflict in the students' approach so that the existing knowledge is not sufficient for solving the problem, thus making it necessary to gain new knowledge and develop new ideas (Breukelen, de Vries & Schure, 2016). During the design process, students are confronted with various tasks and terms, which are complex and / or unknown to them as starting designers A crucial part of technological literacy is understanding design and design process. (International Technology Education Association 2007). It sounds simple but concepts, such as: Designing, Design brief, Designing process are complex, dependent on professional context and difficult to unambiguously define.

Therefore, one of the first tasks of the design project: defining different requirements out of design problems and creating a Design brief of requirements, is a complex task even for experienced designers. Project problem descriptions are often very broadly and subjectively defined, and students are asked to recognize a core design problem and make a design brief or clear research question out of those descriptions.

3.2. Importance of understanding Design brief concept

So why is it important that students make a good design brief? Although opinions differ on Design brief use by designers, for the most of them starting to work on a project from scratch involves making a design brief. The Design brief is a part of the design and project-oriented process used to define tangle of approach, to clarify starting points, to fine tune communication between parties and research on needs and wishes. Part of a design process is recognizing a design problem from client's description. A problem is linked to an unsatisfying situation one has found at the moment. What would be seen as design problem is depending on who would be seen as a problem owner. Therefore, the design problem can be formulated in several ways. This is interesting, as an objective brief therefore could not be made directly from the design problem description. An objective design brief is a trade-off between different perspectives (users, builder and client for example), so that it contains the essence of the question (Roozenburg en Eekels, 1998). But why should the design brief be as measurable and objective as possible? During the design process designer and client could make agreements on design in their consultations. As there are more persons involved and consultation moments decrease in number a more detailed and measurable design brief is needed. That means that with an increasing number of participants in design and a decreasing amount of moments of consultation a Design brief should be more detailed. The level of detail of the requirements should increase as the influence of the client on the design process decreases. Therefore, design brief requirements should be feasible in planning and financial sense, any change would mean more cost or time schedule deviations.

The importance of Design brief is often not recognized by novice designers, as they did not have acquired the necessary knowledge yet. A case study shows that identifying a core of the design problem through design brief requirements directly influence a success of the project (Morkos B., Summers J.D., 2010).

The importance of Design brief can be illustrated by development of expensive software, within building industry, to purchase like BriefBuilder (BriefBuilder bv 2020) emphasizing quality control through requirements management. The Delft Design Guide door Van Boeijen, A., Daalhuizen, J., van der Schoor, R., & Zijlstra, J. (2020) provides, for technology students, a whole chapter about design brief. Starting or experienced designers can find a predetermined method, in the list form, to use. This is not easy. A few steps during completing the list require a certain level of design skill and precedent knowledge about the design and design process.

The definition of Design brief is, just like the definition of design and design process, difficult to unambiguously determine, therefore many definitions are available from different technology disciplines. Although there are lots of possible descriptions on good Design brief, from an already mentioned sources, we can distinguish few criteria needed to make a good Design brief;

Valid - Requirements should be "need – based" and focused on future product not peripheral matters.
Even more important, they should not be about solutions rather than needs.
Vital - The list of requirements can never cover all aspects of the objective and the formulated problem. The number of criteria should be as small as possible to keep focus on the most important needs.

Assessable - The requirements help to make an objective choice; they are operational when different people can judge a design in the same way.
Exclusive - It is not the intention that two or more requirements evaluate the same characteristic of a product / solution.

When looking at the different steps and different criteria of making a good Design brief it becomes clear why having a good design brief is important in the design project. It makes it clear towards both problem-owner and student what is expected of the design result. This is especially important when there are multiple problem- owners with different interests. Making a Design brief helps the students determine which approach to take to the design project, helps in making objective and justified choices throughout the project and gives a clear list of criteria to evaluate their project results on. Defining a Design brief of requirements to design a solution is one of the initial actions within a designing process, which determines the end results (Joshi, Morkos, Shankar, Summers & Mocko, 2012).

3.3. Design brief concept and structure –function reasoning

In design projects the students will often be designing technological artefacts. These technological artefacts perform their function based on their physical structures. The artefacts have a dual nature for they are physical structures that realize intentional human actions (Kroes 2009). Both function and structure should be described for a complete view of the technological artefact. This relationship between function and structure plays a large role when designing these artefacts. Needs and wishes (functions) need to be translated into structures that enable the realization of those functions. (Kroes and Meijers 2000)

As in the design project of R&D students these wishes, needs and expectations stem from the problem-owner, part of the problem identification is finding out what those needs are and writing them down in the design brief. Then the students try to find the structures that enable the realization of those functions in their design. This function-structure reasoning is not easy. In a study by Frederik, Sonneveld and De Vries (2011) technology teachers were asked to examine technological artefacts and write down their structural and functional characteristics. The technology teachers had difficulties distinguishing the two. Teachers listed more structures than functions and often, structural properties would end up in the task (function) column and, although less often, vice versa.

4. THE DESIGN BRIEF CONCEPT CLASROOM EXPERIENCES

Creating a Design brief of requirements is a complex task even for an experienced designer. It is difficult to define different requirements from design problems in a valid, vital, assessable and exclusive way.

But if so, what is than the composition of the requirements that students in the age of 11/12 years recognize when making a Design brief for the very first time? How much they already know about Design brief? What kind of knowledge do they already have? Do they have any pre-knowledge at all? Can we help young designers to make design brief understanding the basic criteria of making it?

To answer these questions, a research strategy was designed based on knowledge upon concept learning strategies of confronting student's ideas, learning by designing and concept-context learning. Pre-knowledge about Design brief and possible concepts were explored so we could confront students' ideas. Next step was to analyze several design briefs made by students with no previous instruction and explanation so we can explore what kind of requirements they are listing when they are designing and making the Design brief for the very first time. The assignment students should base their design brief and design on is an official school design assignment placed in context and written for field professionals. Knowledge gained by the two previous steps will together with theoretical knowledge about the Design brief form a stepping-stone for a possible support tool for teaching novice students the Design brief concept. Chosen research instruments were various; a survey for measuring pre-knowledge and concepts of the Design brief among young students during their very first design project, a case study and sampling to gather facts on design brief composition, mixed method to combine aspects of gained theoretical knowledge and Atlas TI for survey and sample analyses.

4.1. Secondary school students' reasoning about the Design brief

Main goal of the research is to discover how secondary school students reason about the way that a Design brief is created and the purpose of Design brief in general. Obtained information will be used to develop a theory or/

and tools to improve students making and understanding the Design brief. Pre-knowledge about the Design brief of young children just starting with the subject R&D was conducted through a survey. The survey population consisted of three classes (68) students in the age of 11/12 years starting with the R&D subject and their very first design assignment. Two first grade secondary school classes were chosen ad random. The survey set-up was filling out an online questionnaire in an electronic learning environment during a regular R&D lesson at a specific point of time during a design project assignment. Timing set-up was very important because students should be starting with a design assignment but not yet have reached the moment of making a design brief.

Students were asked to answer questions about pre-knowledge of the term design brief, what they think the design brief is, who makes it, why we make it and when and how we make the design brief. Students with no pre-knowledge about the design brief were still asked to write down their concepts. Answers from the questionnaire were coded in Atlas TI. First in vivo coding took place and then data were subjected to another round of coding. In a third round of coding groups and categories were created.

Response rate was 100 % because a survey set-up embedded the questionnaire as a part of the regular lesson.

First of all, around 55% of the students said they have never heard of the term design brief before. Around 5% recognized the term but admitted to not knowing what it meant and a remaining 41% said they had some pre-knowledge about the design brief. The most common source of pre-knowledge is a similar subject or a project in elementary school. Not all students who had pre-knowledge specified what kind of pre-knowledge they had. From the students that did specify most pre-knowledge was about requirements. They had experienced that the design brief listed requirements, either for the design or for the project itself.

When asked what they thought the design brief is, most students referred to requirements in their answer. In Dutch the term for design brief is 'programma van eisen' (literally translates to program of requirements) so requirements were already implied by the term. Thoughts on what the requirements refer to were various. Not all students specified what the requirements refer to, but those who did were divided between requirements for the design (product) and requirements for the project (process).

Not everyone explained the design brief as having something to do with requirements. Some thought the design brief would be helping them plan, stating deadlines, etc. or giving them extra information about what had to be done in the project assignment. There was also a small group of five students who confused the word program with computer program.

The answers to the question of why one makes the design brief were mostly very broad and generic answers. Most of the students were not able to specify. The reasons given can be categorized into three categories, in order of number of responses these are: clarification (about the assignment, expectations, requirements, etc.), delineation (boundaries, rules, etc.) & usefulness (we make it because it will help us).

Students listed many different parties as the maker of the design brief. Never was it suggested that multiple different parties could work together. Most named was the teacher, followed by the client followed by (someone from) the design team. When asked how we make the design brief once again it became clear that students do not think that it is made in collaboration. Most students listed generic ways of making a list (writing it down, typing it on the computer, etc.).

Answers to the question, when to make the design brief during the project, were various. It was difficult to extrapolate from the answers when students think the design brief is made. Most students think it was somewhere in the beginning stages of the project/before you start designing.

Most students think that the design brief has something to do with requirements but opinions are divided on what the requirements are for and why we make it. Students are unsure about when we make the design brief; they are not able to specify parts of the process. They do not know that it is something that is made in collaboration with the different involved parties.

4.2. Design brief case study

In order to discover how secondary school students reason about the way that a Design brief is created, next to a survey, a case study was started to gather samples. While the survey explored pre-knowledge of the students about the Design brief, a case study explores reasoning about requirements and structure-function. Within a school official assignment were a researcher-influenced small number of purposive samples being gathered in order to explore the composition of first-time defined requirements. The set-up for the case study were two regular classes of students R&D. To avoid possible influence, a survey about pre-knowledge and case study were completed in different ad random chosen first grade secondary school classes. Thirty-six students working in nine teams of four were asked to define (per team) the Design brief requirements for the very first time. Timing of gathering samples was crucial. Students should be making their very first design brief at that time. Therefore an embedding of research in school assignment was necessary. Response was a 100 % because of embedding a task into a regular lesson activity. Instruction on making Design brief was not desirable, yet the official school assignment used as case study includes very limited short written instruction on design brief and few (six) assignment requirements. This short instruction on design brief requirements was used as only instruction on Design brief.

4.2.1. Sample analyses

The design brief requirements of nine different R&D teams were analyzed through Atlas TI method. To analyze the responses, they were imported into Atlas Ti. The responses were first coded in vivo. In a second round of (open) coding similar in vivo codes were grouped. In a third round of coding the open codes were put into categories.

Nine-team requirements resulted in a total of 83 items. Some requirements were reoccurring. As this research is not about reoccurring of requirements but about understanding a concept of design brief, all 83 requirements were important for research repeatedly used or not. Nevertheless, reoccurring of requirements can picture how strong teams influence each other by possible copying requirements from each other and from the assignment. Possible taking over without comprehending assignment requirements and repetition of those were important to study because they are directly related to understanding a concept of Design brief. The analyses of requirements were based on repetition of same requirements in different teams, repetition on taking over of assignment requirements, level of description and type of requirement.

4.2.2. Repeatedly occurring requirements

When nine teams are making a design brief from the same assignment an overlap is to be expected. Large overlap could suggest that the assignment is very unambiguously and directive written or that the teams were having big influence on each other's ideas. Nine teams produced 83 requirements in range from 6 to 19 requirements per team with modus of seven and median of eight requirements per team. Surprisingly most of the requirements were not repeated or repeated by two or three teams. More than four teams repeated only two requirements, which make more than 50% of the teams. One of those two, repeated in six teams (67%), is an assignment design brief requirement. Repetition of requirements within different groups is important in relation to taking over without comprehending assignment suggested requirements. There is some overlap with suggested requirements. In eight of nine teams that means one of two requirements out of 6 to 19 with median of eight requirements. One team did not repeat any suggested requirements (0 from 7) and one team repeated five suggested requirements from seven (5 from 7) requirements they made.

In conclusion, the requirements are very various and different per team. Just two requirements are the same and repeatedly occurring in most of the teams. Requirements taken over from assignment and evented are equally represented. Most of the teams were taking over approximately two from six assignment requirements. This means that teams did not influence each other and that the project assignment was not directive formulated. This could also mean that students did not read the assignment (properly), did not take up on assignment instructions or in general did not discuss and share their opinions and assumptions on requirements to make. There is also a possibility, in contrast to request, that just one student within a team was assigned to make a design brief.

4.2.3. Function or structure requirement description

All 83 requirements were after analyses in Atlas TI possible to divide into four groups of requirements related to level of description. The first group represents ambition (function) requirements, which stand for pursuit to better perform on a specific goal. They stand for intentional function. Ambition requirements are generally described, undefined, broad (positive) concepts, such as; durable, comfortable, fast, safe and so on. The second group named solution (structure) requirements stands for requirements, which are already providing a possible solution, such as: window on the front and side, parachute, round capsule with wheels around it, no wheels on the bottom and so on. They already provide on some physical properties/structure. The third group named incomplete (functional) requirements, represent functional requirements, which are valid and exclusive but not always assessable and vital, such as; our design must run on solar energy, no fossil fuels, waterproof, transport of 1-6 persons, cost lower than 30 000 euro and so on. Incomplete requirements represent requirements closest to valid, vital, exclusive and assessable requirements. The fourth group were unclear, ambiguous requirements. These were vague requirements, written in the way they were not readable or understandable, therefore they could not be used for research.

Most of the analysed requirements, almost half of it (47,5%) fitted a description of ambition requirements. Quarter (25%) fitted description of solution requirements and the smallest group (19,5%) were incomplete requirements. There were some unclear requirements (7,3%) as well. The smallest group of requirements were incomplete requirements that describe desired function. Therefore they were valid and exclusive but not always vital and assessable. Most of the design brief requirements of R&D teams turned to be very general. Terms like nice, not expensive, quick, comfortable, and ecological were used to describe properties of the new vehicle to design. They are not describing the structure of the future artefact but ambition on intentional function. They do pictures student's ambitions about a product to make. Therefore they are not assessable.

A quarter of student design brief requirements were solution requirements. This emphasizes that relation between function and structure plays a large role when designing artefacts. Students were trying to reason from the function or ambition on function that is subjectively desired by designer to a physical form that enables the realization of that function. That is not surprising because previous studies showed that designers are often trying to reason from the function that is desired to a physical make-up that enables the realization of that function taking into account the human and social needs, hopes and expectations (functions) and the physical resources we have available and can adapt (structures) to meet those hopes and needs (Frederik, Sonneveld, De Vries, 2011). In the student design briefs that were examined in this pilot study it is evident that many students are also not able to distinguish the difference between function and structure. Many requirements stated are already solutions, they are thinking of the structures that will give them the desired functions instead of listing functions. Therefore they are not valid.

It is clear that starting secondary school, student designers are thinking (in order of importance) first of all in Design brief terms that are picturing their ambition on function about a product/artefact to design, than of the

structures that will give them the desired functions of the product/artefact to design and as last about functions of the product/artefact to design. In general most of the requirements were exclusive and vital but not valid and assessable.

4.2.4. Type of requirement

What types of requirements did novice designers most frequently use? After division of requirements on level of description a division of requirements based on type of requirement took place.

All 83 requirements were after analyses in Atlas TI possible to divide in several groups of requirements related to: environment, safety, position, cost, function, appearance and use. More than half of requirements (48) fitted a type of requirement describing use of design product like, having a lots of space, self-driving, TV built to the wall, self-filling fridge…Safety (11) and environment (9) were following far less often chosen as requirement. Appearance (7), function (5) en cost (2) are the categories with lowest number of requirements. Analysing de student's data just one social and one economical requirement appeared. Social or economical distinguishing such as; social context, stakeholders, different users, costs or other economical requirements seem to be unimportant to novice student designers. In conclusion, by far the largest number of requirements fits use of product type of the requirement, a user context.

5. DISCUSSION

Although results correspond to everyday practice a different student group could unexpectedly provide different results. Of course this is just one case study and results might differ using another R&D teacher description of the same assignment, type of project or design assignment angle. Focus of research was to explore existing knowledge of students and their capability and ways of making a design brief. Focus did not extend on formulating and understanding a design problem because of young age of the students.

6. CONCLUSION

It is clear that starting secondary school student designers have almost no Design brief pre-knowledge. Research data showed lack of pre-knowledge about the design brief in contrast to various concepts. Most students' think that the design brief has something to do with requirements but opinions are divided on what the requirements are for and why we make it. So there are no general pre-concepts found. Students are unsure about when we make the Design brief; they are not able to specify parts of the process. They do not know that it is something that is made in collaboration with the different involved parties. Students also do not recognize a connection between Design brief and design results. R&D teachers in general experiences with novice R&D designers, pupils in the age around eleven/twelve, show very incomplete and general descriptions as Design brief requirements. When students are asked to make design brief requirements based on very limited explanation within official assignment requirements, their requirements are very various and differ per team. Expected high overlap in requirements per team because of possible taking over requirements from assignment is not higher than 20% -30% and equally represented through teams. That most of the requirements are not valid and not assessable. Student's requirements are formed out of future product user point of view. First of all requirements are written in Design brief terms that are picturing their ambition on function about a product/artefact to design, than of the structures that will give them the desired functions of product/artefact to design and as last about functions of product/artefact to design. Therefore most of the design brief requirements of R&D student teams turned to be very general. Terms like nice, not expensive, quick, comfortable, and ecological were used to describe properties of the new vehicle to design. They are not describing the structure of a future artefact but ambition on function. They do picture students' ambitions about a product to make. The smallest group of requirements were incomplete requirements that describe desired function. Function and structure are not equally represented. Emphases is on ambition/ intention of function and function it self. This could be explained by fact that structural description already restricts solution space. Other explanation could be that designers are of young age with no precedent knowledge in designing and therefore no knowledge about structure properties.

7. POSSIBLE IMPLEMENTATION

When giving form to possible intervention on learning concept of Design brief, based on this case study, we can presume that students don't have much pre-knowledge on Design brief concept but when asked they come with almost personally attached various concepts. In order to avoid forming of misconceptions students various concepts should be acknowledged and anticipated. Students should also be provided by knowledge on connection between Design brief and design results, when, who and why we make Design brief at all. This knowledge should be growing and being enriched through constant changing of context within each design assignment project of R&D providing a new angle on the concept of Design brief and learning by design experience. To improve validity of requirements and assessment of requirements a responsive teaching tool could be developed giving students freedom to learn from their mistakes. For example; after students already made the Design brief by themselves a support tool or /and a discussion can be provided to improve exclusivity, vitality validity and assessment of the requirements. Special attention should be given to validity and assessment of requirements as we could learn from our case study that the most of the requirement made by students were not valid and assessable. On the end of the project an informal learning through reflection on use of requirements, influence on design product and their usefulness during a design should take place because by recognizing ways of own thinking and experiences the student is improving awareness of strengths, limitations, gained knowledge and skills. Results of the case study show that students are designing from their own vision of future product user. To improve thinking about requirements from different angles a role-play visualisation (different roles or characters) could take place.

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Practical research based on Goldberg Simple Machinery Project on the cultivation of Engineering Thinking of high school general technology

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Abstract

With the rapid development of STEAM education, engineering education has become particularly important.The "General Technology Curriculum Standard for Ordinary High Schools",which was published in 2017 in China, proposes five core competences in the subject, with engineering thinking being one of them. This shows that cultivating students' engineering thinking ability in high school is of great significance.The author creatively took the design and production of Goldberg Simple Machinery Project as the course carrier, driven by tasks, and aimed at solving problems. In teaching design, the theory and practice were organically integrated and the complementary advantages of the theory and practice were achieved in teaching practice activities.Moreover, the effectiveness of project-based teaching in cultivating students' engineering thinking has been verified through this practice. Meanwhile, some experience and a few shortcomings have been summarized .And these shortcomings need to be further improved to better serve teaching.

Key words:Goldberg Simple Machinery,General Technology of High School,engineering thinking, core competence

1. INTRODUCTION

With the rapid development of STEAM education, engineering education has become particularly important. The "General Technology Curriculum Standard for Ordinary High Schools",which was published in 2017 in China,proposes five core competences in the subject(Ministry of Education of the People's Republic of China,et al.,2020), with engineering thinking being one of them.This shows that cultivating students' engineering thinking ability in high school is of great significance.

So, what is engineering thinking? Engineering thinking is a planning thinking centered on system analysis and comparative trade-off.It requires students to understand the diversity and complexity of system and engineering;Be able to use the method of system analysis to analyze elements,conceive the scheme,and compare the trade-off in a specific technical field; Understand the practical application of basic concepts and methods of structure, process, system, and control, and be able to use them for simple decision analysis and performance evaluation.(Ministry of Education of the People's Republic of China,et al.,2020).

In fact, how to cultivate students' engineering thinking depends on the teacher's cognition.At first, the teacher lacked a thorough understanding of engineering thinking and ignored its importance, so she did not consciously cultivate students' engineering thinking through practical activities. Although the curriculum standard establishes five levels of engineering thinking and corresponding content ,the teacher evaluated students' engineering thinking just only based on their mastery of the knowledge and skills covered in the textbook.The knowledge and skills involved in engineering thinking are detailed in Table 1.

Table 1.
The knowledge and skills content involved in engineering thinking

Knowledge Theme	*Details of knowledge content*
Fundamentals of Technology and Design	*The relationship between design and technology; General principles of design*
The general process of design	*Identify and clarify issues;Design Analysis;concept design;Compare and weigh design options;design evaluation;Optimize design scheme;Material selection and planning;Tool selection and planning*
Structure and Design	*analysis of the structure;Relationship between structure and function;Simple structural design and optimization*
Process and Design	*Process expression;Basic factors considered;process analysis;Simple Process Design and Optimization*
System and Design	*System analysis process;systemic analysis method;System Design and Optimization*
Control and Design	*Elements of Control;Control measures and methods;Control System Design and Optimization*

2. LITERATURE REVIEW

However, with the in-depth study of curriculum standard, the teacher has realized that cultivating students' engineering thinking must rely on systematic practical activities.At present, the teachers lack practical teaching carriers for the cultivation of general technology engineering thinking for students,while cultivating engineering thinking of students requires experiencing a complete engineering project(Wang Lu,et al.,2023).

The teacher takes "DIY creative design" project as the carrier, based on real-life problems, let students propose,analyse and solve problems on their own. Through the entire project practice process, they learn and experience the "general process of design", pay attention to the coherence and completeness of the project, and ultimately achieve the goal of cultivating students' engineering thinking.(Xu Yan,2019).Research has shown that "robot teaching" projects also have advantages in cultivating students' engineering thinking development(Ruan Wulin,2024).Using Goldberg Simple Machinery Project as a carrier to conduct practical research on general technology teaching can guide students to solve problems in real situations and cultivate their engineering thinking(Wang Lu,et al.,2023).The research also chooses the design and production of the Goldberg Simple Machinery Project as the course carrier. In addition to cultivating students' engineering thinking, it can also review the "general process of design", achieving complementary advantages between theory and practice, and making the general technology course full of fun(Pan Biyun,2021).The specific operation process is shown in Figure 1:

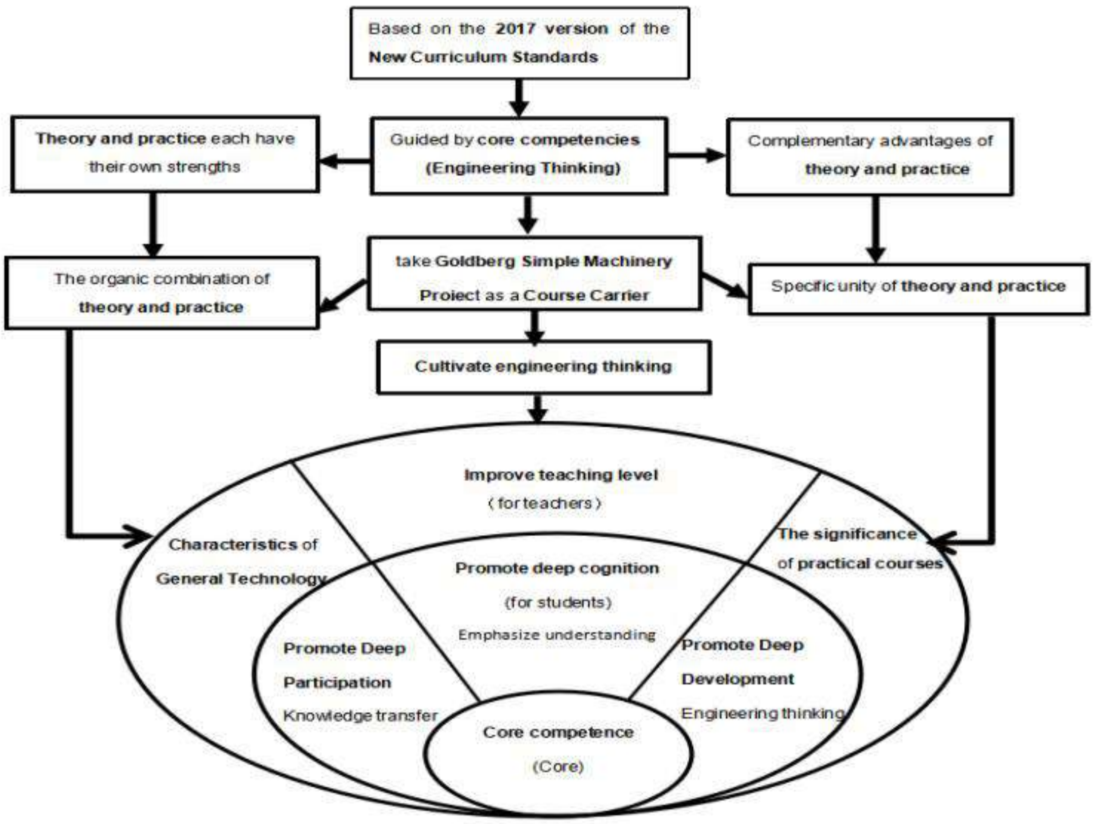

Figure 1. Design and Production Operation Process of Goldberg Simple Machinery Project

3. METHODOLOGY

This research,which was conducted under the guidance of constructivism theory and the "General Technology Curriculum Standard for Ordinary High Schools", mainly adpoted the action research method.At that time, the teacher selected four classes students in the second year of high school as the research subjects.

Because the curriculum standard proposed to cultivate students' engineering thinking, the teacher initially taught based on the five levels of engineering thinking levels determined by the curriculum standard and the corresponding content of the textbook, but the effect is not significant. with the in-depth study of curriculum standard, the teacher realized that cultivating students' engineering thinking must rely on systematic practical activities. So, the teacher introduced Goldberg Simple Machinery Project into the classroom.

Based on this activity, the teacher determined the teaching path:

Firstly, teaching analysis. Taking scientific decision-making as the goal, reversed analyze teaching content, objects, and objectives to form the basis for teaching design. To ensure the smooth progress of this research, the teacher should have the ability to integrate subject knowledge and teaching knowledge into curriculum teaching.That is to say, the teacher needs to process, transform, express, and impart knowledge to students in a way that is easy for students to understand,which is the PCK theory,and the concept of it was introduced by Shulman (1986).

Secondly, preparation for teaching**.** Developed the learning process and prepared the necessary conditions for teaching.

Thirdly, teaching implementation. Based on constructivism, the teaching setting included creating situation, knowledge guidance, project analysis, design and production, knowledge internalization, and sharing and evaluation, guiding students to experience embodied learning through "embodied experience, knowledge internalization ,reflection and improvement", realizing the entire process of project implementation, and cultivating students' risk assessment and decision-making abilities through iterative practice.

Fourth, expand teaching. Around the three dimensions of "knowledge strengthening," "project upgrading," and "ability enhancement," the teacher aimed to promote students' mastery of the concepts, methods, and skills of general technology, and enriched their engineering thinking system.((Ma Zhongjiang,et al.,2024).

4. IMPLEMENTATION OF GOLDBERG SIMPLE MACHINERY

4.1. Theory and practice each have their own strengths

General technology is a relatively broad technology except for information technology ,which reflects foundational and universal characteristics and is distinct from professional technology. It is a widely used technology in daily life and has broad migration value for the development of students. In essence, general technology course is a course based on practice, emphasizing creativity, highly comprehensive, and integrating science and humanities.Its learning process is a process in which students actively construct knowledge, constantly expand their abilities, and form good emotional attitudes and values. It is an activity process full of vitality, full of exploration and diversified ways.However, the traditional teaching model is teacher-centered to impart theoretical knowledge, and students can only passively accept it, which goes against the original intention of the curriculum design.

Rube Goldberg Machinery is a precision and complex device designed to accomplish very simple tasks in a convoluted manner(Yang Ying,2019),like pouring a cup of tea, beating an egg, turning on a switch or raising a flag, etc. In order for this device to accurately complete a task, it requires the designer to make comprehensive use of the knowledge they have learned during the design process. Of course, when the teacher use Goldberg Simple Machinery as a medium for teaching, she does not ask students to design a simple machinery device by themselves, but rather to have students repeatedly study and use materials and tools at hand to imitate and make this device.The production process of Goldberg Simple Machinery is aimed at specific tasks,formulate specific design scheme, make specific structures,test and optimize to form a stable mechanical system. In fact, it is a process of comprehensively applying knowledge of general technology .

4.2. The organic combination of theory and practice

After studying the 2017 edition of the new curriculum standard, we can see that the guiding ideology of education is to focus on human development and put forward the concept of " Core competence ". Core competence of general technology mainly includes: technology awareness, engineering thinking, innovative design, technical drawing and materialization ability. Core competence is the concentrated embodiment of the educational value of a subject, which is the correct values, essential qualities, and key abilities gradually formed by students through subject learning.

In quality-oriented classroom teaching, the teacher has introduced the design and production activities of Goldberg's Simple Machinery, with the aim of providing students with a practical platform to apply theory to practice and promote the digestion and absorption of knowledge.This practical activity not only helps students review the general process of design and master the processing techniques of metal or woodworking, but also makes up for the shortcomings of theoretical teaching only based on paper and without hands-on practical operations,which increases the interest of learning and cultivates students' engineering thinking and hands-on abilities.

How are the five core competences reflected through Goldberg Simple Machinery, and in what stages are they reflected? How to apply the knowledge from textbooks to achieve the design goals of Goldberg Simple Machinery? Table 2 provides a detailed explanation of the above issues.

Table 2.
Implementation Points of technology Core competences

Core competence	*Teaching aims*	*Application of textbook knowledge*
Technology awareness	In the process of imitation design and production, students should respect originality, pay attention to environmental protection, and have a sense of safety and responsibility	Technology and Design 1(Gu Jianjun,2020) 1. General principles of design 2. General process of design
Engineering thinking	*Students can use the method of system analysis to compare and weigh design solutions. Be able to comprehend basic thinking methods such as structure, process, system, and control, and apply them effectively*	*Technology and Design 1:* *1.The conception method of the scheme;* *2.Comparison and weigh*

		of scheme Technology and Design 2(Gu Jianjun,2020)*: Comprehensive knowledge application*
Innovative design	*In the process of imitation, students comprehensively use the knowledge of various disciplines to innovate and design, including technical innovation on the basis of others' schemes*	*The nature of technology: 1. Comprehensive; 2. Innovation*
Technical drawing	Students are required to watch the video repeatedly and then submit a complete design proposal in groups. At the same time, each group should write out the general process of the design and draw technical drawings	*1. General process of design: 2. (1) Drawing of technical drawings (2) Mechanical processing diagram*
Materialization ability	*Finally, students convert the scheme into items.*	*1. Metal processing technique 2. Wood processing technique 3. Test evaluation and optimization*

4.3. Complementary advantages of theory and practice

Goldberg simple machinery may seem easy, but designing and producing a precise and complex system is not an easy task.In view of the students' practical ability, the practical class is mainly imitation.

Students were required to watch the video repeatedly and then submitted a complete design proposal in groups. At the same time, each group should write out the general process of the design and draw technical drawings. Finally, they should try to use the materials in their hands to make the devices in the video and achieve specific functions. Of course, innovation was encouraged in the actual operation process.

Take the production of "raising flags" as an example to realize the complementary advantages of concept and practice. The teaching process is shown in Figure 2:

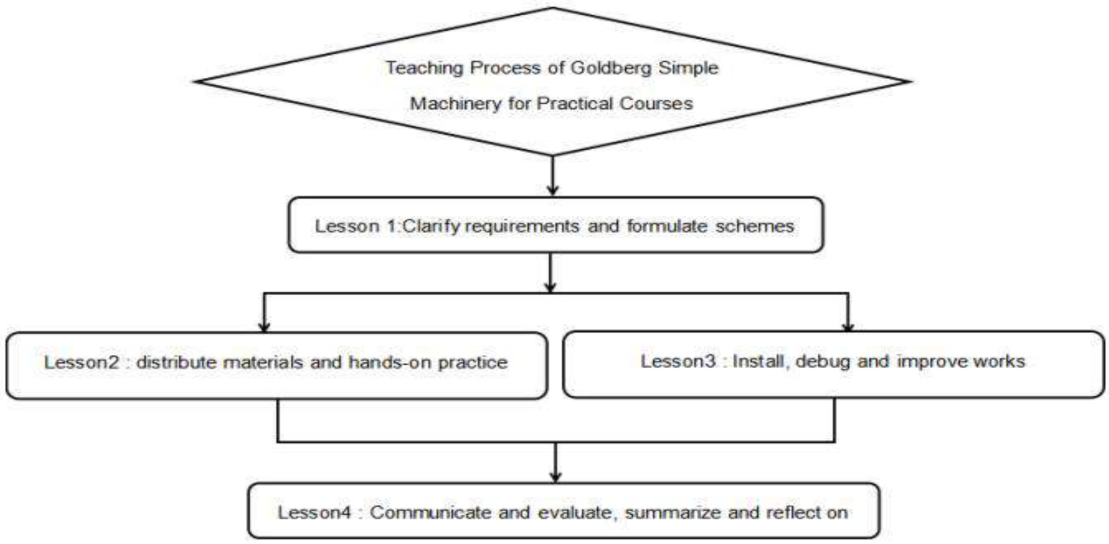

Figure 2. *Teaching flowchart*

4.3.1. Lesson 1:Clarify requirements and formulate schemes

Table 3.
score and deduct points

Score（no limit）	*Deduct points*
10 points are added to complete each part of the mechanical structure	*Not submitting the design proposal, each group will lose 10 points*

Can successfully raise the flag, add 50 points *Later beautification, add 10 points* *Designed your own team flag, adding 10 points* *Identify the structural type and force situation, and add 2 points each time*	*The finished product does not match the design scheme ， reducing 50 points* *20 points will be deducted each time for influencing others to display, making loud noises, and damaging the environment*

***Table 4**.*
Scheme table

Name________Class _______ Group ______	*remarks*
Design sketch (drawing, dimensions, notes)	
Materials used	

Figure 3. *Students are watching the video carefully*

Figure 4. *Students begin to formulate design schemes*

In Lesson 1, emphasis was placed on cultivating students' abilities in "technology awareness," "engineering thinking," "innovative design," and "technical drawing".

4.3.2. Lesson 2:Distribute materials, hands-on practice

Materials provided by teachers:Each group had a hard paper shell of the same size, a ruler, a small knife, a hot melt glue gun, an unlimited supply of glue sticks, a magnet, a marble, a nut, and a balloon.

Materials prepared by students themselves:Two bamboo sticks (or chopsticks), two straws, a plastic bottle, a hollow hard paper tube in the middle of toilet paper (as it was difficult to find, you could make your own paper tube or use other materials instead, as long as it did not affect the effect).Individual groups had prepared colored cardboard or pigments to beautify the final works.

The students began to actively create according to the plan, which could be said to be the Eight Immortals crossing the sea and showcasing their respective abilities. During this period, the teacher was mainly responsible for answering questions, providing assistance, managing discipline, and reminding students to pay attention to safety.

Figure 5.

Figure 6.

In Figure 5 and Figure 6, the students began to make each link according to the design scheme and the processing flow.

4.3.3. Lesson 3: Install, debug and improve works

After the active efforts of the first two classes, most groups were able to submit their works by the end of this class; Some groups wanted to strive for excellence and used their noon time to improve their works. This practical course has truly stimulated students' enthusiasm and interest in learning technology.

Figure 7.Students are improving their works

Figure 8 Students begin to install and debug their works

4.3.4.Lesson 4: Communicate and evaluate, summarize and reflect

Figure 9.

Figure 10.

Figure11.

Figure 12.

Figures 9 to 12 are displays of partially completed or unfinished works.

Figure 9 is the work of group 1. This group is all boys, they are very thoughtful and have strong hands-on abilities.At the very beginning, the team leader clearly defined the division of labor ,so they were able to achieve unity and cooperation throughout the entire production process. Although there were also differences during the production process, it was the spark of wisdom generated by the collision of such ideas that they completed the task efficiently, with high quality and quickly.Unfortunately, their Goldberg Simple Machinery device was not very smooth when raising the flag, and further improvement and optimization were needed.

Figures 10 and 12 are both groups of girls. Although practical classes are a form of exercise for them,it is not a small challenge. Fortunately, they could try to overcome difficulties and complete tasks on time.

Figure 11, this group is the one with the most abundant self-prepared materials. Due to many choices and ideas, their speed was affected and they failed to complete the task on time in class. But they strongly demanded using their lunch break to complete their own production, and this spirit is commendable.

With the deepening of teaching and continuous reflection on this practical activity,the teacher found it unreasonable to evaluate students' engineering thinking solely based on their knowledge acquisition from the textbook or evaluate students' engineering thinking from the level hierarchy of curriculum standard. Instead,it is more reasonable to evaluate engineering thinking from the perspective of students' ability development laws. So the teacher divided engineering thinking into a three-level structure of cognition, behavior, and thought. The corresponding indicators from low to high are analytical comprehension, innovative design, and scientific decision-making, and provide specific descriptions based on the level and content of engineering thinking (see Table 5)(Ma Zhongjiang,et al.,2024).

After students handed in their finished products, the teacher would score, select, and reward them according to Table 5.

Table 5.
The three-level structure and level hierarchy of engineering thinking [3-5]

	First level structure: Analytical comprehension	Second level structure: Innovative design	Third level structure: Scientific decision-making
Level 1	Through experiencing the general process of technical design, preliminary multi-factor analysis of the design scheme, understand the system analysis methods of comparison, trade-off and optimization; through typical case analysis, perception, system and engineering phenomena, understand the basic characteristics of the system	———	Explore and explain how the input, process, output and various factors affect the system, form a preliminary engineering awareness and thinking
Level 2	Be able to analyze design cases in conjunction with the system, summarize and generalize methods for system design	Be able to use system, structure, process, control and other principles and analysis methods to conduct simple technical activities,and attempt to solve technical problems;Be able to determine a simple object of life and production, analyze the factors that affect the system,try to optimize the system by changing the input, process, output, feedback, and interference	———
Level 3	Be able to use the method of system analysis on a clear technical problem in some specific technical field	Identify the characteristics and details of technical problems, clear constraints and various influencing factors, and propose possible solutions	Try to use simulation experiments or mathematical models to consider various influencing factors, and to conduct decision analysis and performance evaluation
Level 4	———	Be able to apply systematic analysis to complex problem scenarios in a certain technical field , make it specific ,form possible solutions and continuously optimize and improve design	Be able to initially use a simple, simulation experiment or mathematical model for performance and risk assessment, improve the decision-making ability and develop engineering thinking
Level 5		Ability to integrate and apply knowledge from science, technology, mathematics, engineering, and other fields and colligate multiple technical fields for system analysis and options design	Use simulation experiment or mathematical model to evaluate the design scheme, and optimize and improve it through trend analysis and risk assessment

Besides engineering thinking,the materialization ability of core competences has also been fully reflected in this practical activity. It has been proven that as long as you provide a platform for students, they will surprise you with their abilities.While completing the practical project and achieving learning objectives,the students also consolidated the knowledge of processing techniques for different materials in the textbook Technology and Design 2.They collectively expressed that practical activities made textbook knowledge more concrete, deepened their understanding and memory of knowledge, and changed their learning methods. Therefore,they hope to have more such practical activities in the future.

4.4. Specific unity of theory and practice

The design and production activity of Goldberg Simple Machinery Project, which lasted for four lessons, has come to an end.This type of teaching activity ,which takes a perfect practical project as a course carrier and helps students to review knowledge and master basic skills step by step, is worth promoting.First,it makes up for the shortcomings of traditional teaching models. Secondly, it achieves a concrete unity between theory and practice.

5. RESULTS AND DISCUSSION

The activity theme of Goldberg Simple Machinery Project is clear, interesting, and challenging, whose design philosophy is to complicate simple problems.It requires participants to design and complete a complex system within a limited time and make all parts to work together to achieve functionality,which may take students too much time to complete or even exceed their ability.So the premise of this kind of practical activities is that the teacher lets students watch , imitate and make a Goldberg Simple Machinery device according to the video, rather than designing a device themselves, because the difficulty of the two is completely different.Students are willing to actively participate, which makes the activity easy to promote. Meanwhile,the materials used in the activity are familiar to students, easily accessible and cost-effective and the tools in our practical classroom can meet the needs of students' production.

Returning to the connotation of engineering thinking, it is a type of planning thinking. Because the materials used in activities have relatively low processing difficulty, students can focus more on how to plan activities, which also highlights the focus of teaching.

Goldberg Simple Machinery Project is a great teaching practice carrier. As for its effectiveness of teaching, teachers should take into account the overall applicability of the students. Because different regions, student levels, and hardware conditions of different schools will definitely have different implementation effects. Therefore, practical activities should also be tailored to local conditions.

Taking Goldberg Simple Machinery Project as a teaching carrier has the following benefits besides cultivating students' engineering thinking:

(i) It can not only exercise students' hands-on abilities, but also help them develop good qualities and communication skills such as cooperation, sharing, and proactive progress;
(ii) It is beneficial for cultivating students' ability to collect and process information;
(iii) It is conducive to cultivating students' ability to discover and solve problems, enabling them to gain rich experience in hands-on practice, and stimulating their innovative potential;
(iv) It contributes to promoting a fundamental transformation in students' learning methods.

6. CONCLUSION

The problems faced by human beings in the future will certainly be complex and challenging. Simple knowledge and skills can only stay at the level of manufacturing, and it is difficult to rise to the level of intelligent innovation. In order to cope with the uncertain challenges of the future, the education oriented to cultivate people-oriented and engineering thinking is imperative. Students can really have the engineering thinking ability only through the real field under the real problem solutions, from Analytical comprehension, innovative design, scientific decision-making three angles, repeatedly to find and solve the reality training, in the process of design, testing, iteration constantly summary reflection improvement.

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Technology and Engineering Education in Primary and Secondary Schools Under the Background of "Holistic Education": Implications, Values, and Paths

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Abstract

Under the educational philosophy of "holistic education" the integration of technology and engineering education in primary and secondary schools is essential for nurturing students' core competencies, fulfilling societal expectations for shaping professional engineering attitudes, and serving as the foundation for enhancing individual innovative and practical abilities. Technology and engineering education empower the "holistic education" (moral, intellectual, physical, aesthetic, and labor education) respectively, expanding new perspectives on the integration of the "holistic education" and indirectly achieving the new goals of comprehensive human cultivation. Under the backdrop of "holistic education" the integration of technology and engineering education in primary and secondary schools must follow the new path of "vertical integration, learning and creation fusion, and integration of science and education" to ensure steady and long-term progress.

Key Words : Primary and secondary schools, Technology and engineering education, Holistic education

1. INTRODUCTION

In the process of steadily advancing the construction of a strong country in science and technology, advanced technologies serve as the cornerstone for building engineering projects, much like how multiple facets come together to form a three-dimensional whole, collectively shaping a new image of national creativity. At the National Education Conference, President Xi Jinping emphasized the importance of "firmly focusing on the fundamental task of cultivating moral character and fostering individuals who are well-rounded in moral, intellectual, physical, aesthetic, and labor education (holistic educations) to become socialist builders and successors." He also proposed the development goal of "steadily progressing towards the strategic objective of building an education powerhouse." At the second session of the 14th National People's Congress meeting focused on livelihood issues, Minister of Education Huai Jinpeng highlighted the significant progress made in STEM education and engineering-related disciplines such as science, technology, medicine, and agriculture in recent years. He pointed out that the key to "enhancing capabilities and improving quality" lies in further implementing "holistic education" and extending the comprehensive cultivation system of "moral, intellectual, physical, aesthetic, and labor education" along with the development of high-quality teaching materials. Therefore, a thorough analysis of how TEE can foster students' core competencies will provide an important perspective for fully understanding the practical significance of "holistic education."

2. INTEGRATED TECHNOLOGY AND ENGINEERING EDUCATION：INTERPRETING THE ESSENCE OF "HOLISTIC EDUCATION"

Technology and engineering are materialized practical activities through which humans optimize their environment, improve nature, and create an artificial world (Gu, 2023). The cultivation objectives of "holistic education" have consistently been integrated into the steady development of basic education. Incorporating new elements of TEE within this framework can more profoundly interpret the specific requirements for modern talent cultivation and core competencies under the backdrop of a view of science and technology.

2.1. What the nation requires — cultivating students' core competencies

TEE integrates the principles of science and technology with practical engineering skills, providing students with a fertile ground for more personalized and socialized cultivation. While technology is centered on exploration and discovery (Xing & Wang, 2021), engineering focuses on applying technology to solve practical problems and produce tangible products and implementations (Bai, 2019). The tacit knowledge conveyed by TEE—which comprises internalized and non-systematic practical experiences and insights—constructs a bidirectional pathway for the development and internalization of competencies.

Internationally, educational policies in various countries emphasize the cultivation of competencies. For example, the United States' Every Student Succeeds Act (U.S. Department of Education, 2015), the K-12 Technological and Engineering Literacy Standards: The Role of Technology and Engineering in STEM Education (International Technology and Engineering Educators Association, 2018), and the European Union's European Education Area (European Commission, 2020) strategy all highlight the attention given to competency-based education. Similarly, the Ministry of Education in China has promoted the Core Competencies for the Development of Chinese Students (Bame et al, 1993), which underscores the focus and investment in competency education. “Holistic education,” as a key area for cultivating students’ comprehensive qualities, fundamentally integrates technological and engineering elements, providing new “living water sources” for the restructuring of students’ comprehensive competencies and their overall development.

2.2. What society hopes for — shaping professional engineering attitudes

On the other hand, the development and leadership of contemporary science and technology are driving a new round of industrial upgrading and societal progress. Frontier technologies such as AIGC, large-scale AI model applications, big data, and cloud computing are not only reshaping people’s living habits but also providing new catalysts for economic growth. Research indicates that students’ experiences with engineering education in school are directly related to their career interests, as these experiences shape their views on engineering and technology (Bame et al, 1993). In fields such as TEE and STEM education, educational departments are dedicated to enhancing students’ scientific literacy and technical practical abilities, promoting advancements in basic education within the realm of technology and engineering, thus fostering new talents capable of internalizing knowledge into skills.

The nurturing environment of TEE in primary and secondary schools helps students engage with authentic technological research and engineering challenges during their foundational educational phase. By training design thinking and problem-solving capabilities, it cultivates an engineer’s mindset, laying a solid foundation for future careers. Moreover, TEE education promotes gender equality and social inclusivity, encouraging a more diverse student population to participate in STEM fields, which is crucial for shaping a technologically and engineering-oriented workforce.

2.3. What individuals excel in — strengthening innovative practical abilities

In the pursuit of high-level self-reliance and strength in science and technology, the new generation of students needs to acquire new skills in individual innovation and construction to adapt to the rapidly changing technological environment and societal demands. The interrelation between innovation and practice can be likened to the interdependence among moral education, intellectual education, physical education, aesthetic education, and labor education within the framework of “holistic education.” Both illustrate the core elements of talent cultivation within the educational system.

Just as moral and intellectual education jointly build students’ comprehensive character and cognitive structure, physical education and aesthetic education promote their harmonious physical and mental development alongside an enhancement of artistic appreciation. Labor education is dedicated to forging students’ diligence and practical operational skills. Similarly, embedding TEE within the “holistic education” framework can not only enhance students’ practical operational abilities and complex problem-solving techniques but also stimulate their intrinsic innovative drive.

3. VALUE RESTRUCTURING：COMPREHENSIVE EMPOWERMENT THROUGH “HOLISTIC EDUCATION” IN PRIMARY AND SECONDARY SCHOOL TECHNOLOGY AND ENGINEERING EDUCATION

With the continuous deepening and development of modern educational philosophies, educational goals have gradually shifted towards the comprehensive cultivation of students’ overall qualities. The concept of “holistic education” emphasizes the positive role that each aspect plays in the development of the others, seeking holistic generation of content and competencies through transformative integrative forms (Li & Zheng, 2022). This not only serves as an important guiding principle for educational policymakers but also provides educators with a new perspective and practical framework. The comprehensive empowerment of TEE in primary and secondary schools, embodied by “holistic education,” not only enhances students’ intellectual and technical skills through systematic knowledge transmission and practical operations (intellectual education), but it also stresses the cultivation of good moral qualities and social responsibility (moral education), healthy physical and psychological well-being (physical education), aesthetic appreciation and innovative creativity (aesthetic education), as well as practical operational abilities and a spirit of labor (labor education). This integrative approach promotes harmonious development in students’ moral, intellectual, physical, aesthetic, and labor aspects, laying a solid foundation for their lifelong learning and all-around development.

3.1. Moral education: cultivating ethical character and social responsibility

The intersection of moral education and TEE in primary and secondary schools is, in essence, a dialogue between humanities and science, spirit and reason. Moral education focuses on shaping students’ cognition, emotion, will, and actions, paying attention to the cultivation of internal values and ethical behavioral norms; while TEE emphasize the stimulation of practical abilities and innovative thinking, helping students master methods and technologies for solving real-world problems. On the surface, these two areas may seem unrelated, but in fact, they have profound intrinsic connections and rich educational significance. For example, introducing data ethics and cybersecurity education into information technology courses can not only enhance students’ awareness of self-protection in the digital realm but also deepen their understanding of social responsibilities such as respecting others’ privacy. Through participating in technological projects involving public interests, such as designing intelligent transportation systems, students can directly feel the close connection between their technical capabilities and national development strategies, thereby enhancing their sense of social responsibility and mission. This experiential learning method helps deepen students' understanding and application abilities (Dewey, 1938) and lays a solid foundation for their future careers.

3.2. Intellectual education：enhancing scientific and interdisciplinary capabilities

The scope of intellectual education in the primary and secondary school stages covers fundamental subjects such as Chinese, mathematics, English, natural sciences (physics, chemistry, biology), social sciences (politics, history, geography), information technology, arts, and physical; whereas TEE focus on "making" and "doing," engaging students through hands-on, design-based approaches (Guan, 2023). The relationship between TEE and intellectual education in K-12 settings is far more complex than a simple inclusion or being included. The intricate interaction and interweaving of the two make their boundaries blurry and difficult to define clearly. From an academic perspective, this relationship reflects the interdependence of subject areas and the multiplicity of educational goals. The relationship between the two should be viewed as a dynamic, mutually reinforcing complex system rather than a static, single-dimensional hierarchical structure. TEE deepen the content of mathematics, physics, and chemistry, while also adding a new dimension to the cultivation of engineering literacy. From a theoretical standpoint, this interdisciplinary integration embodies the concept of holistic education, promoting the comprehensive development of cognitive, emotional, and social skills in primary and secondary school students by integrating knowledge from different fields (Smith, 2018).

3.3. Physical education：strengthening physical health and psychological resilience

Currently, our country places great emphasis on the health of all citizens, particularly the physical fitness of young people, which has become an integral part of the national strategy. A series of related policies promulgated by the state, such as the "National Fitness Program (2021-2025)" and the "Healthy China Initiative (2019-2030)," emphasize the importance of physical exercise in improving the overall health level of the population (State Council of the People's Republic of China, 2019, 2021). Physical health is not only the foundation for the comprehensive development of individuals but also a key factor in the long-term development of the nation. Excellent physical fitness can significantly enhance an individual's quality of life and health status, as well as increase their psychological resilience, allowing them to demonstrate higher coping abilities and mental stability when facing various challenges in daily life.

TEE provide strong support for the development of smart sports. With advancements in information technology, intelligent devices and software platforms are widely applied in physical education, enriching the forms of teaching in PE classes and enhancing the scientific rigor and effectiveness of training. Through data analysis, physical education teachers can gain a more precise understanding of students' physical conditions and athletic performance, thereby formulating personalized training plans.

3.4. Aesthetic education：nurturing aesthetic sensibility and humanistic care

Aesthetic education not only cultivates students' aesthetic appreciation, humanistic qualities, and innovative thinking abilities but also holds an indispensable position in the process of individual growth (Liu et al, 2023). Elliot Eisner emphasized in his book "The Arts and the Creation of Mind" that art education is one of the key factors in stimulating students' creative thinking (Eisner, 2002). However, due to the uneven distribution of educational resources and the bias in the current evaluation system, aesthetic education has not received the attention commensurate with its value during its implementation.

On the surface, TEE and aesthetic education appear to belong to two entirely different domains: the former emphasizes rigorous logical reasoning and the cultivation of practical operational skills, while the latter focuses on emotional experiences and the cultivation of humanistic values. However, there is actually a complementary intrinsic connection between the two. TEE can be seen as a "rigid" category, emphasizing the rigor of structure and function; whereas aesthetic education is viewed as a "flexible" dimension, focusing on the beauty of form and emotional resonance. This unique integration mechanism of "softening the hard" and "harmonizing hardness and softness" embodied in embedding elements of aesthetic education into TEE can enrich students' innovative thinking patterns, enhance their humanistic qualities, and transform pure instruction into practical applications (Li & Cheng, 2018). Howard Gardner, in his book "Frames of Mind: The Theory of Multiple Intelligences," elucidated the critical role of diversified intelligences, including artistic intelligence, in the overall development of students (Gardner, 1983).

3.5. Labor education：reinforcing labor skills and practical abilities

Labor education, as an essential component of holistic education, has continuously enriched and developed its connotations. The environment for labor education has expanded from traditional classrooms to exploratory communities, shifting its stance from "consolidating fundamentals" to "integrating knowledge across disciplines." Its functions have evolved from "a tool for survival" to "self-actualization," and its forms have transitioned from "single-subject" to "educational ecology" (Zhou & Ding, 2024).

Labor, technology, and engineering together form the foundation of modern production and innovation activities. Labor is the fundamental means of creating value, encompassing not only physical exertion but also contributions of intellectual wisdom. Technology is a key factor in improving labor efficiency and expanding production scale, making labor more efficient and precise through the application of tools, methods, and knowledge. Engineering, as the bridge between technology and practice, transforms abstract design concepts into tangible products and services. “Labor” provides the drive, “technology” endows the capability, and “engineering” realizes the value. The complementary nature of labor education and TEE together promotes the formation of students' labor concepts and enhances their practical abilities, achieving an organic integration of “labor,” “technology,” and “engineering.”

4. IMPLEMENTATION PATH：BUILDING A “HOLISTIC EDUCATION” AND TEE SYMBIOTIC MECHANISM

Amidst the intertwining tides of globalization and informatization, China’s education sector has actively responded to calls from all sides, aiming to cultivate versatile talents suited to the trends of the era. However, in the process of realizing this grand vision, TEE at the primary and secondary school levels still face numerous practical challenges. Given this, it is necessary to review the development path of TEE in primary and secondary schools from a higher perspective, exploring the intrinsic links between this field and the “holistic educations.” This is not only an innovative attempt in modern educational theory but also a commitment to fostering the core competencies of future citizens.

4.1. Top-to-bottom integration: efficient connection between top-level system design and dynamic execution at the grassroots level

Primary and secondary education in China has clearly proposed and practiced scientific and technical education, but for a long time, engineering education has remained elusive (Zhou & Ding, 2024). When examining the differences between STEM education in China and the United States, it becomes apparent that although China’s primary and secondary schools have clear directions and abundant practices in science, TEE, they have yet to form a systematic approach to engineering education. In contrast, the success of STEM education in the United States is largely attributed to the efficient alignment from top-level design to grassroots implementation, with the core of this alignment being “integration” (Gu & Wang, 2017).

To achieve a coherent vision from top to bottom, it is first necessary for the national level to formulate clear policy orientations and establish specialized institutions to coordinate planning, ensuring that educational goals are implemented from a macro-strategic level down to specific operational details. There must also be reasonable allocation of existing educational resources and the construction of cross-departmental collaboration mechanisms to promote information exchange and technical support. At the same time, greater autonomy should be granted to grassroots schools to encourage them to explore and adopt innovative integration methods to adapt to the rapidly changing technological environment and societal needs. Teachers’ mindsets and roles need to be redefined, with educators becoming mentors and supporters in the students' exploration process.

4.2. Integration of learning and innovation: interaction that promotes solid theoretical study and bold innovative practice

Under the educational philosophy of “holistic educations,” the “integration of learning and creation” in primary and secondary school TEE emphasizes the close combination of theory and practice. Specifically, primary and secondary schools can audioize university textbooks, organize industrial robot science camps, and set up hands-on simulation experiments with programmable logic controllers (PLC), encouraging students to apply their acquired knowledge to solve real-world problems in nearly authentic environments.

“Learning and creation integration” should promote interdisciplinary cooperation, breaking down barriers between subjects, encouraging students from different backgrounds and regions to form teams and jointly complete comprehensive projects. Such projects should be based on the current primary and secondary school curriculum system, with their content designed to fit students’ “zone of proximal development,” covering areas such as technical design innovation and engineering verification. Meanwhile, efforts should be made to strengthen the faculty team, introducing “dual-qualified” teachers and enhancing the professional technical skills and innovation capabilities of the existing faculty.

4.3. Convergence of education and research: deep integration of educational implementation and the development of scientific research

Currently, many primary and secondary schools place great importance on educational research, using it to improve school education and enhance teacher competence (Ding, 2014. While education and research in primary and secondary school settings each have their distinct roles, they are intertwined, dedicated to cultivating students’ comprehensive qualities and laying the foundation for basic academic abilities. Research activities, conducted under the guidance of teachers, involve concrete practices of scientific inquiry or innovative projects. They tend to focus on personalized exploration and discovery, aimed at stimulating students’ innovative consciousness and practical abilities. Overall, education serves as a broad platform for the dissemination of knowledge, covering all students through general learning activities; research extends this individual exploration into specific fields, guiding students to delve deeper into the unknown. These two aspects complement each other, jointly promoting the completion and development of students' cognitive structures.

In the implementation of primary and secondary education, to enable students to understand the significance of education and the value of research more profoundly requires a high-level thinking approach. Comprehensive ethical respect is also an indispensable aspect of the cultivation process. Schools and society should work together to create an environment that respects science and the fruits of others' labor, teaching students not only to pursue progress in knowledge and technology but also to understand how to use these responsibly, ensuring they serve the overall interests of society.

Guided by the principle of "holistic education" TEE in primary and secondary schools not only promotes the comprehensive development of students but also lays a solid foundation of talent for China's efforts to build itself into a technological powerhouse and achieve high-level technological independence and strength, thereby contributing to the historical process of the great rejuvenation of the Chinese nation.

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Robotics application research in K12 education: A systematic literature review

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Abstract

In recent years, robotics, as an emerging form of teaching and learning, has received increasing attention in the field of education. The number of related studies has been emerging. To summarize the advantages and shortcomings of robotics application in K12 education, we used the systematic literature review method to screen out 59 high-quality literature. We also further quantitatively analyzed and visually presented the selected literature in six dimensions: overall trends in robotics application in educational research, research contexts, teaching philosophies, teaching strategies, teaching effectiveness, and the knowledge involved. The results of the review indicate that robotics application research in K12 education has received widespread attention in recent years, mainly in elementary schools with less than 60 students, with generally a few experimental rounds and short implementation lengths, aiming to cultivate students' creativity and practical skills, and focusing on collaborative inquiry-based teaching strategies and hybrid teaching content delivery. In terms of teaching effectiveness, the focus is on the improvement of students' cognitive abilities. In future studies, more attention should be paid to medium- and long-term large sample studies to expand the depth of research; develop personalized teaching strategies to promote students' creative practical skills; return to the essence of education and deepen research on diversified evaluation systems; refine robotics education standards and deepen research on robotics subjects.

Keywords: robotics application; K12 education; literature review; teaching strategies

1. INTRODUCTION

With the continuous development of artificial intelligence technology and robotics, robotics applications have penetrated various fields such as industry, agriculture, military, and medical care. Robotics education is an effective teaching method to fully involve students in science, technology, engineering, and mathematics. Its practical nature promotes students' creativity and practical skills (Hakim et al., 2022). Because the flexibility and expansion of robotics application in education are extremely valuable for students’ development, it has been widely used in K12 education (Xia & Zhong, 2018). Robotics application in education has attracted educational practitioners' and researchers’ attention (Papadopoulos et al., 2020). It has shown that the use of robotics could stimulate students' learning interest and self-efficacy, which can lead them to STEM-related jobs in the future (Gomoll et al., 2016). Many studies have shown that students' interest in robotics, programming, and computational thinking is fully stimulated when engaging in robot designing and constructing activities, which in turn promotes their learning (Bers et al., 2014). Robotics applications in education could enhance students’ learning motivation and performance.

2. LITERATURE REVIEW

There has been an increasing amount of research on robotics applications in education. Analyzing the current research status is helpful to guide us to the right direction for future robotics applications in education. Toh et al. (2016) analyzed the role of robots in early childhood education and lower-level education. The results indicated that the effects of robots on children's skill development could be grouped into four main categories: cognitive, conceptual, language, and collaborative skills. Xia and Zhong (2018) found that despite the great potential of robotics for K12 education, it did not result in significant improvements in students’ learning. They recommended that more design-based intervention studies could be conducted. Papadopoulos et al. (2020) reviewed the research on the use of Socially Assistive Robots and found that studies focusing on mathematics and science are significantly under-represented. They did not provide a systematic review of the status of robotics applications in K12 education. Hence, the current study reviewed the status of robotics application research in K12 education to provide references for robotics-supported teaching practice. Specifically, this review aims to explore the following issues.

(i) What are the research contexts of robotics application in K12 education?
(ii) What are the teaching philosophies guiding robotics application in K12 education?
(iii) What are the teaching strategies in robotics supported K12 education?
(iv) What is the teaching effectiveness of robotics supported K12 education?
(v) What is the knowledge involved in robotics supported K12 education?

3. METHODOLOGY

This paper uses a systematic literature review approach to conduct the study, which includes the following steps: problem identification, criteria development, literature search, literature screening, data extraction, statistical analysis, and review writing.

After identifying the literature to be analyzed, the literature was coded and analyzed using coding criteria in five areas: research contexts, teaching philosophies, teaching strategies, teaching effectiveness, and knowledge involved.

3.1. Literature selection method

This study reviews research papers related to robotics-supported education published in international academic journals in the past 23 years (2000-2022). Web of Science, ERIC, EBSCO, and Wiley Online Library were used as the main literature databases. Two sets of keywords were used as search terms in any combination. The first group of keywords includes "robot*". The second group of keywords was education-related keywords, such as "education, learn*, class*, teach*", and so on. Through the initial reading and general screening of the literature, a total of 196 papers were obtained. According to the purpose of the study, the researcher further screened the initial literature in detail. The steps were as follows: (1) the literature should be robotics education-related research, excluding pure robotics engineering research; (2) the research should be conducted in K12 education (including pre-school, elementary school, secondary school, etc.); (3) the peer-reviewed journal literature was selected, excluding research papers such as dissertations, conferences, and monographs. According to the above selection criteria, 59 papers were selected from Computers & Education, Journal of Science Education and Technology, Interactive Learning Environments, Educational Technology & Society, Journal of Engineering Education, IEEE Transactions on Education, and other journals on educational technology.

3.2. Coding analysis method

Considering that the research contexts, teaching philosophies, teaching strategies, teaching effectiveness, and the knowledge involved are the main concerning areas for researchers, in-depth analysis and review of these five areas can provide theoretical and methodological support for future research on robotics education. Therefore, a preliminary literature coding framework was constructed for this study. The coding framework was refined by referring to existing review articles and trial coding of several pieces of literature. The final coding framework was formed as shown in Table 1. The researcher used the literature coding framework to quantitatively code the final selected 59 papers. The coding framework consists of the following five dimensions: research contexts, teaching philosophies, teaching strategies, teaching effectiveness, and knowledge involved. Each dimension was further subdivided according to the specific details to demonstrate the status of robotics education research in K12 education. This analysis is helpful to guide future robotics-related research.

Table 1.
Coding framework

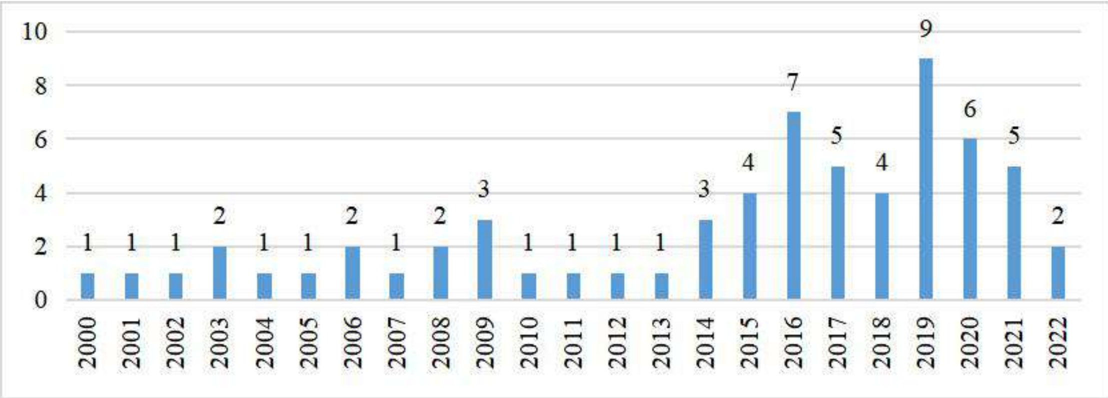
First level dimension	*Secondary Dimension*	*Description*
Research contexts	*Implementation period*	*Pre-school, Elementary School, Middle School, High School*
	Sample size	*<60 people, 60-90 people, 90-300 people, >300 people*
	Duration of each instructional implementation	*0~1 hour, 1~3 hours, More than 3 hours*
	Number of teaching implementations	*Less than 5 times, 5~20 times, More than 20 times*
	Data collection method	*Quizzes and tests, Classroom observation, Questionnaires*
Teaching philosophies	*Emphasis on interdisciplinarity and knowledge transfer*	*Focus on students' ability to transfer and integrate knowledge*
	Focus on students' learning interest	*Focus on the appeal of teaching activities to students*
	Emphasis on collaborative learning among students	*Focus on students' ability to collaborate and communicate*
	Emphasis on hands-on practice	*Focus on students' hands-on practice ability*
	Emphasis on creative skills	*Focus on students' creative ability cultivation*
Teaching strategies	*Simulation exercises*	*Practice through simulated experiments*
	Collaborative inquiry	*Collaborative inquiry to complete related learning tasks*
	Inspiring innovation	*Inspire innovation through task-driven learning*
Teaching effectiveness	*Cognitive ability*	*Computational thinking, problem solving skills, reasoning skills*
	Social skills	*Collaboration, communication, organization and management skills*
	Practical skills	*Operational and practical skills*
	Motivation and satisfaction	*Learning motivation, self-efficacy, learning satisfaction*
Knowledge involved	*Programming algorithms (thinking, software)*	*Integration with programming knowledge*
	Operation practice (hardware)	*Integration with hardware manipulation skills*
	Robotics theory knowledge	*Designed to transfer knowledge of robotics theory*
	Hybrid content	*Integration of programming, operational, and theoretical knowledge*

4. RESULTS

4.1. Overall trend

As shown in Figure 1, the development of robotics education application research reached a peak in 2016. The first peak in 2016 was based on the rise of the concept of "artificial intelligence + education" and the gradual popularization of robotics education programs. The second peak was observed in 2019. This phenomenon is in line with the prediction of the 2017 Horizon Report (K12 Edition).

Figure 1.
Overall publication trends in robotics education research over the past 23 years.



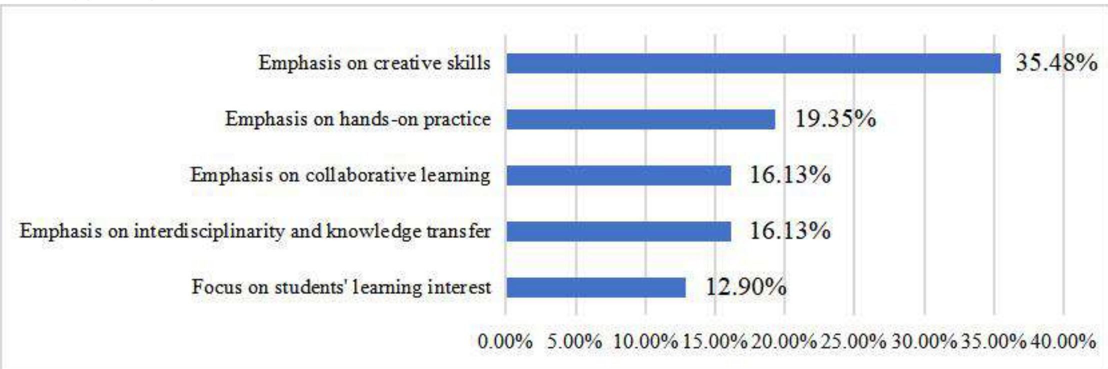
4.2. Research contexts

As shown in Figure 2a, the current robotics educational application is mainly involved in elementary, high school, preschool, and middle school (in order of percentage). The sample size was predominantly less than 60 students (n = 14, 73.68%) and 60-90 students (n = 4, 21.05%) (as shown in Figure 2b). The duration of each implementation was mainly 1-3 hours (n = 23, 79.31%) and 0-1 hour (n = 5, 17.24%) (as shown in Figure 2c). The number of implementations was predominantly less than 5 (n = 17, 53.13%) and 5-20 (n = 14, 43.75%), with the least number of implementations above 20 (n = 1, 3.13%) (as shown in Figure 2d), indicating that most of the robotics education application studies were based on short-term interventions. Questionnaires (n = 11, 39.29%), tests and assessments (n = 10, 35.71%), and classroom observations (n = 7, 25%) were the predominant data collection methods (as shown in Figure 2e).

4.3. Teaching philosophies

The teaching philosophy of focusing on the development of students' creativity was the most widely studied in robotics education (n = 11, accounting for 35.48%) (Noh & Lee, 2020), followed by hands-on practical skills (n = 6, accounting for 19.35%), emphasis on collaborative learning among students (n = 5, accounting for 16.13%), and subject integration and knowledge transfer (n = 5, accounting for 16.13%), as well as students' learning interest (n = 4, 12.90%) (shown in Figure 3). This is consistent with the basic orientation of robotics applications in education, which aims to cultivate students' creative thinking and hands-on practical skills.

Figure 3.
Teaching philosophies.



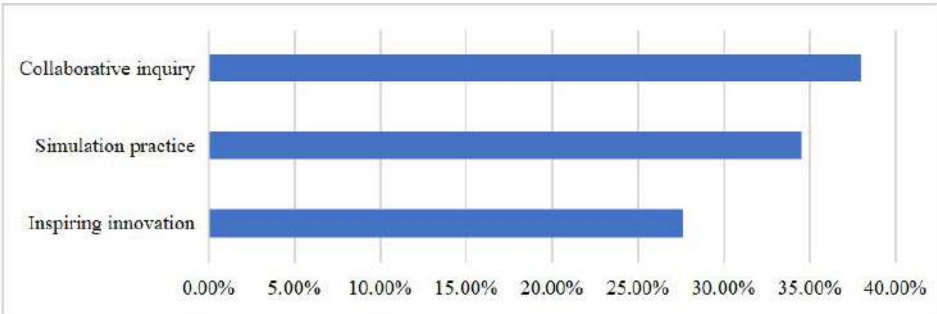
4.4. Teaching strategies

In terms of teaching strategies, the review indicated that the main teaching strategies applied in robotics-supported education were collaborative inquiry, simulation practice, and inspiring innovation. Collaborative inquiry instruction promotes students' collaborative communication skills, exploration, and creative abilities. It accounts for the highest percentage in robotics education research (n = 11, 37.93%) (as shown in Figure 4). This result is consistent with the notion that robotics education application emphasizes the development of students' collaborative inquiry and creative practice skills.

Simulation practice is used to practice robotic programming through computers and external development boards, such as Arduino, Lego, and mind+, etc., which are programmed to control the external devices. Simulation practice is a common strategy for robotics education at the K12 education level (n = 10, 34.48%).

Moreover, Inspiring creativity teaching strategy aims to promote students' creativity practice skills through heuristic learning tasks (n = 8, 27.59%).

Figure 4.
Teaching strategies.



4.5. Teaching effectiveness

Teaching effectiveness, a key indicator of successful instruction, has received much attention from researchers. Through a review, the robotics teaching effectiveness focus on four main areas: cognitive skills, social skills, practical skills, motivation, and learning satisfaction. Some studies focused on multiple teaching effectiveness simultaneously. Duplicate counting was performed. Among them, 44 (61.97%) focused on the effects of robotics education on students' cognitive development, 14 (19.72%) focused on students' social skills cultivation, 11 (15.49%) focused on students' motivation and learning satisfaction, and 2 (2.82%) focused on students' practical skills (as shown in Figure 5).

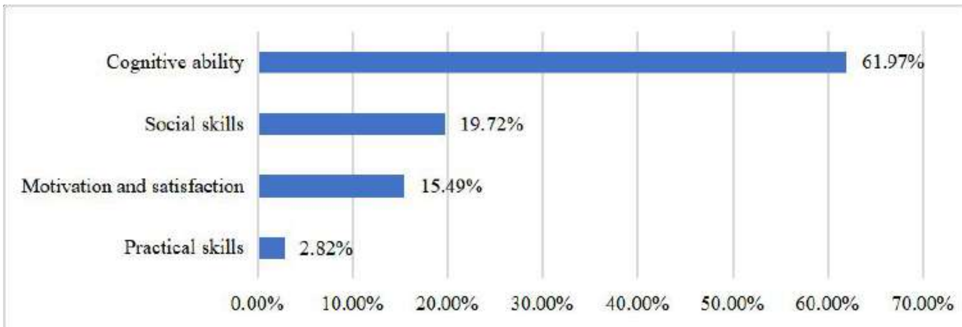
In terms of cognitive skills, many studies supported that the use of robotics promotes students' cognitive skills such as subject knowledge, computational thinking, and creative thinking.

Collaborative learning is a common robotics learning method. It has a beneficial effect on students' social skills (Zhong & Xia, 2020).

The use of robotics in education has a facilitating effect on students' learning attitudes and motivation. Motivation itself is a challenging task. The facilitative effect of robotics application on student motivation is not only related to the use of robots but also closely related to the instructional design and guidance methods.

In existing studies, robotics is often combined with programming education in a task-driven method. The hands-on training enhanced students' practical skills. For example, Okita (2014) found that the use of robotics promotes students' knowledge application and problem-solving skills.

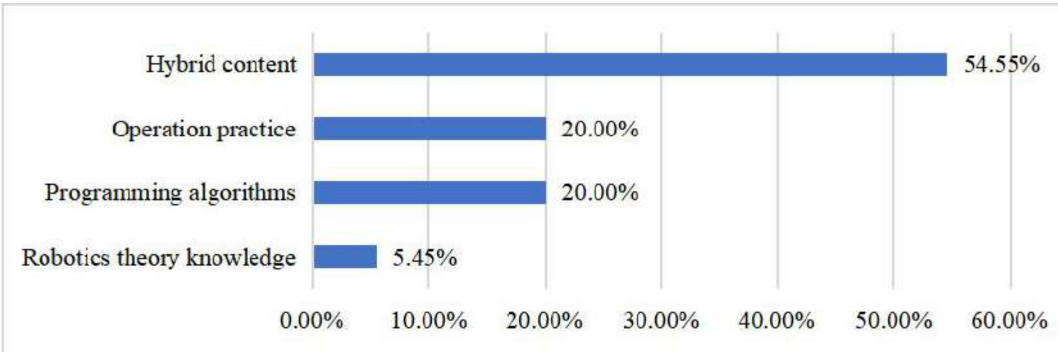
Figure 5.
Teaching effectiveness.



4.6. Knowledge involved

The current content of robotics applications in K12 education is mainly hybrid content (n = 30, 54.55%). Hybrid content refers to a mixture of theoretical and practical knowledge of robotics; followed by hands-on practice (n = 11, 20%) and programming algorithms (n = 11, 20%), while pure theoretical knowledge of robotics is the least (n = 3, 5.45%), as shown in Figure 6. These contents were distributed across the school levels.

Figure 6.
Knowledge involved.



At the preschool level, the curriculum content of robotics education mostly mixes theory, software, and hardware. Manipulative gamification learning is the main instructional method. The education at this stage focuses on cultivating students' computational thinking and operational practice skills. It involves less professional theoretical knowledge (Chen et al., 2020). At the elementary education level, robotics-supported education mostly consists of theoretical knowledge and operational practice (n = 11, 52.38%), focusing on cultivating students' computational thinking and hands-on practical skills. In terms of practical skills development, it is mainly based on visual programming platforms, such as Scratch, and off-the-shelf hardware sets, such as Lego, to carry out inquiry-based learning to develop students' creative and practical skills (n = 5, 23.81%) (Chevalier et al., 2022; Kucuk & Sisman, 2017). Compared to the elementary level, the knowledge at the middle and high school levels is more systematic, requiring students to establish goals, analyze problems, abstract models, and solve problems (Cuperman & Verner, 2018). Some of the content integrates science, mathematics, and other disciplines with robotics to promote students' interdisciplinary skills development (Cassidy & Puttick, 2022). A mixture of theoretical and practical content is predominant at the middle and high school levels (n = 14, 53.84%). The curriculum at this level involves relatively specialized knowledge of specific programming languages and algorithms, no longer just modular visual programming. The course design is often integrated with 3D, microcontrollers, and electronic component control. In the teaching process, the teaching content will be closer to the analysis and solution of real problems, such as hardware assembly, device programming and functional debugging, etc. These learning activities are integrative and could be used to train students' overall planning skills. Teaching at this stage also organizes competition projects systematically. But Xia and Zhong (2018) proposed that robotics education at the secondary level lacks a mature curriculum system and practical guidance.

5. DISCUSSION

5.1. Focus on medium and long-term large-sample research to expand the depth of research

The research contexts analysis reveals that current robotics education research focuses mainly on small samples (< 60 students), with less than five rounds of short-term studies. This research context could lead to problems such as a lack of depth and generalizability of the research findings. Therefore, to further expand the depth of research and deepen robotics education application research, we can further focus on robotics education application research at the middle school in the future.. Robotics-supported education, as an important carrier for the cultivation of computational thinking, could be widely carried out in middle school to promote students' computational thinking and creative practical skills. Moreover, existing studies are mainly short-term studies with small samples. Hence, we could further expand the sample size and conduct more medium- and long-term studies in the future to reduce the interference caused by the novelty of robotics technology, improving the reliability and generalizability of robotics applications in education studies. It could provide theoretical and practical support for future robotics applications in educational studies.

5.2. Develop personalized teaching strategies to promote students' creative practical skills

Developing students' creative and practical skills is the main guiding philosophy of current robotics education research. Guided by this teaching philosophy, the main instructional strategies used in robotics-supported education research are collaborative inquiry, simulation practice, and inspiring innovation. Among them, the collaborative inquiry is the most widely used, followed by simulation practice, and inspiring innovation. Appropriate teaching strategies are key to determining teaching effectiveness (Chevalie et al., 2022). Collaborative inquiry is an instructional approach in which students work together in small groups to inquire while participating in a learning activity or completing a learning task.

Simulation practice is more hands-on than traditional lecture-based teaching. It could provide strategic support for robotics-related learning in K12 education. Inspiring innovation is to promote students' creative thinking development through inspiring teaching. Moreover, based on inspiring innovation, collaborative inquiry and simulation practice can be integrated to help students develop collaborative inquiry and practical innovation skills through inspiring exploration. Robotics-supported learning is exploratory in nature. Different teaching strategies can be used for students with different knowledge levels. Therefore, guided by students' needs, robotics teaching strategies could make full use of the interactivity and intelligence of robots, focusing on students' subjectivity to stimulate their inquiry interest and promote robotics learning effectiveness.

5.3. Return to the essence of education and deepen research on the diversified evaluation system

Educational evaluation is an important part of educational practice. It also has a significant guiding effect on educational practice. The main problem of current robotics-supported education effectiveness is that it is mainly at the cognitive level, and its effects at the practical level are less obvious. One of the reasons may be that practical skills are difficult to measure with traditional methods. To effectively solve this problem and improve the scientific evaluation system of robotics education, we should return to the essence of education and strengthen the construction of a diversified evaluation system. The current evaluation methods in robotics education application research are mainly based on achievement tests and questionnaires.

It is difficult to determine whether it is improved or not by test scores. Moreover, questionnaires are somewhat subjective, and it is difficult to objectively reflect the effects of robotics learning. Therefore, the robotics teaching effectiveness evaluation methods could be diversified. For example, classroom observation, work analysis, and questionnaires can be used in combination to evaluate students' robotics teaching effectiveness from multiple perspectives. Before learning evaluation, scientific instruments could be used to ensure the scientific nature of the evaluation. We should emphasize students' ontological status and substantive evaluation closely related to robotics education.

5.4. Refine robotics education standards and deepen research on robotics subjects

From the results of the literature review, the applications of robotics in K12 education are divided into two main categories, namely robotics-assisted learning, and robotics discipline learning. Among them, robot-assisted learning is dominant. It focused on the use of robots to provide cognitive, affective, or behavioral support for other disciplines of education. In contrast, there is less research on robotics applied to humanities and social sciences. In the future, we can make full use of the diversified functions of robots and explore in-depth the integration of robots with literature, art, and other courses. It is helpful to deepen robot-supported teaching research and provide references for future robot applications in education.

In contrast, robotics discipline education means that robotics is viewed as a subject that is taught as a specialized course. Students can acquire basic knowledge and skills about robotics. In the reviewed literature, there are few studies on robotics discipline education. One reason explaining this result is that the current standards for robotics discipline education did not mature yet. The syllabus and teaching objectives for each stage lack systematic scientific guidance. It has led to a mix of robotics textbooks in the market with wide differences in difficulty.

Robotics provides new opportunities for social change in the intelligent era. The popularization of robotics education applications is the foundation for the cultivation of talents in the age of intelligence. The review results also confirmed the contribution of robotics in enhancing students' cognition, socialization, motivation, satisfaction, and practical skills. However, there is no mature standard for robotics application in education, resulting in a lack of systematic guidance of K12 robotics education. In the future, we can further deepen the research on robotics teaching standards in K12 education and provide systematic and scientific guidance for K12 robotics teaching.

6. IMPLICATIONS AND CONCLUSION

The study analyzed 59 high-quality literature published from 2000 to 2022 to gain insight into the status and problems of robotics application in K12 education research in six aspects: publication trends, research contexts, teaching philosophies, teaching strategies, teaching effectiveness, and knowledge involved. It provided a reference for future robotics education research, including sample selection, teaching design, strategy development, evaluation method selection, and content arrangement. However, there are two shortcomings in this study, such as the limited number of articles reviewed, and the coding framework was developed from the researcher's perspective with less consideration for students. The sample size of the review could be further expanded in future studies. We could also focus on the needs of students in the future development of the coding framework. Despite these shortcomings, this study presented a relatively comprehensive picture of the status and shortcomings of the current robotics applications in K12 education research. It provides a reference for teachers' robotics teaching design and points the direction for future robotics education research.

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A Delphi consensus checklist for assessing Arts design: A case for miniature robots in a STEAM contest

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Abstract:

Arts design has been proven to enable designers to have a meaningful learning of STEAM, but research on a checklist for assessing Arts design based on evaluating entries in a STEAM contest is still rare. Therefore, this study developed a checklist for assessing Arts design for evaluating miniature robots in a STEAM contest. Using an example of STEAM contest, named PowerTech, which has been held 22 years in Taiwan, we developed five dimensions of the checklist are: aesthetics, material usage, bionic, performance, and additional devices. There are two sub-indices in each aspect to be considered as the identification of form characteristics. Eight international experts were invited to review the content validity of the Arts design scale, and 30 completed checklists were used to test the reliability and validity though Kendall's coefficient of concordance. The results showed that the Arts design scale had high reliability and good validity, and so rubric index could be used to measure and assess Arts design with miniature robots in that integrated STEAM contest. Based on this, it is suggested that educational authorities can refer this study and for encourage students to create Arts in any integrated STEAM contests.

Keywords: Arts design · Miniature robots · STEAM contest · Checklist

1. INTRODUCTION

"Arts" as a synonym for project-based learning or design-based learning (Bequette & Bequette, 2012) has been considered an "effective educational strategy"(Park et al., 2016) to boost the integrating knowledge to build students' capability to effectively learn STEAM knowledge (Wu, 2022). As evaluative judgments to STEM works implies for students' behavior in a subsequent learning cycle, or their effects on achievement (Rakovic et al., 2022). In the design thinking process, Imbler et al. (in press) indicated that evaluation instruments affect students meaningful learning; for example, detailed assessment criteria lead to clear expectations and provide opportunities for students to self-monitor, practice and receive feedback (Albay & Eisma, 2021). Art worlds and craft worlds may be distinct, but individual may combine one category with the other over time (Lena, 2019). When these combinations occur, art is conceptualized as higher status than craft (Wohl, 2021). In line with this, to produce miniature model integrates STEAM elements which inevitably emphasizing on the "Arts" rating and making their technological artefacts unique and moveable for relay-racing in PowerTech contest (Hong et al., in press). However, few studies have focused on Arts assessment criteria and checklist in a hands-on oriented contest in which participants make miniature robots to explore the arts component.

Checklist index provide guidance that will allow students to complete the task more effectively, and if instruments are well-designed, they will have an effect on creativity (Tromp & Baer, 2022). Moreover, the criteria, performance levels and quality definitions for each of the assessment activities contribute to project works (Rieger et al., 2020). However, Imbler et al. (in press) noted the existence of structural inadequacies in the methods of analytic grading which invalidate domain- work assessments. These premises ensured that two outcomes of this study: (a) how the Arts assessors validated the checklist for miniature robots in the PowerTech contest, and (b) how they used the checklist after first validating it. To achieve this, the present study aimed to develop a structure and criteria for Arts assessors to evaluate arts design in the PowerTech contest.

2. THEORETICAL BACKGROUNDS

Design activity is multi-disciplinary with multi-group cross, human-centered and technical support-based complex systems engineering (Wang et al., 2020). Barlex (2004) suggested that in the context of school-based design, pupils' design activities could be described in terms of making five types of interrelated design decisions: (a) conceptual, (b) marketing, (c) technical, (d) aesthetic, and (e) constructional. Aesthetic decisions are concerned with what the design will look like. Design activity happens in every design node and iteration, and the inter-connectedness is an important feature of making design decisions (Barlex, 2004; Pirzadeh, 2020). It can be represented visually with each type of decision at a corner of a pentagon, and each corner is connected to every other corner. In this study we considered the characteristics of the STEAM competition to further research and finally designed a new checklist for assessing the Arts of miniature robots.

Due to Barlex's model is in a relatively static and steady condition to focus on aesthetics in school-based design with static projects, then PowerTech contest needs to consider the aesthetics of different angles to ensure the miniature robots balance, move smoothly, and so on. Accordingly, the assessment checklist of Arts of miniature robots in the PowerTech contest at least include (1) aesthetics. This means that after students have completed their original artifacts, they have to add materials to design aesthetic elements. Secondly, the "constructional" aspect of Arts in the PowerTech contest is design material which related to the sophistication of material processes (2). Thirdly, the "technical" aspect of Arts in PowerTech is artifact performance (3) and bionic (4). Lastly, some elements should be considered, such as imitation of animals, dexterity of outlook, and adding light/sound effects from the original product architecture that will be scored as the arts design competition. It was summarized as additional devices (5). The five basic elements are illustrated as follows.

2.1. Aesthetics

Aesthetics was originally intertwined with design and art, but has recently been used to imply different things in different discipline. some frequently used standards are organized as follows, where the words in parentheses are the original aesthetics rule (Cai et al., 2003). The aesthetics principles of shape include: 1) Sense of stability (stability and legerity), 2) Sense of symmetry (symmetry and balance), and 3) Sense of going with a swing (rhythm and cadence). The aesthetics principles of color include: 1) Sense of contrast (contrast and harmony) and 2) Sense of being stationary (stability and legerity). However, there has been little progress in the formulation of a coherent theory with respect to the aesthetic aspect of design (Alfakhri et al., 2018; Veryzer, 1993). These principles are commonly referred as the Gestalt Rules. There are a large number of these rules, which include an emphasis on symmetry, proximity, similarity, continuance, repetition, and closure (Crilly et al., 2004). Thus, those elements are major concerns in this arts design competition.

2.2. Design Material

The material dimension concerns the mediational role of material tools in the group's entire design process. In the present context, we use the term "design material" in a generic sense to refer to the combination of the physical properties of the material and the kinds of representation that the material allows for. Importantly, this research is not only interested in the static or passive properties of design materials per se, but in how the dynamics of materials-in-use differentially affect cognition and collaboration in creative design practice. By referring to miniature robots as a "design material," rather than as a "tool" or a "medium," the research highlights the types of socio-material interaction and cognition they allow for. Therefore, this study addressed the concern by analyzing how the group of participants used design material in their joint creative process. In the analyzed empirical case, the miniature robot material served as a co-design tool for group creation, as it externalized the participants' creative efforts by means of drawings and writings.

2.3. Artifact Performance

The operator of the artifact must carry out the quality assessment of behavior of the robot system. After the simulation has been completed and the relation of simulation results has been obtained, it is important to assess the performance, which is based on the analysis of parameters such as: 1) liveliness (possibility to move in a flowing and continuous way), 2) reduction of the influence of "bottle-necks" on the performance of the artifact, 3) succession of destinations of transporting, and 4) possibility to effect better sequences of modeled operations (Kost & Zdanowicz, 2005). The third and fourth parameters in the Power Tech contest were assessed in the competition of relay racing and tug-of-war. Then, the liveliness and the moving flow were evaluated as the artifacts' performance.

2.4. Bionic

Modeling and simulation play a critical role in both robotics and technological contest research processes. Bionics of autonomous models and robots present a unique and difficult challenge. It is difficult to simulate the physics of a robot realistically, and the transfer from artifact simulation to the real animal is not always simple (Hohl et al., 2006). In this Power Tech contest, the present robotic systems were characterized by high simulation that required thinking about the influence of gear ratios, and especially for the harmonic movement, gears and driving parts could generalize forces to link with immovable parts (Mostyn & Skarupa, 2004), then make the artifact move in accordance with the designers' wishes, which was considered in the assessment.

2.5. Additional devices

In designing artifacts, designers have to make sure that they adhere to given sets of design requirements and constraints. In constraint-based design, optimization approaches have been developed by Gonzalez-Zugasti and Otto (2000) to design product platforms and families of variants. Adding more functions under the constraints may create new object versions. It is, therefore, necessary to allow the creation by modification or adding extra materials to the original constraints. Initial design constraints are given by the contest regulations and represent the wishes with respect to solving the contradictory problems in the functional, structural, and physical aspects of the artifact. In addition to the wishes, the additional generalized forces producing more functions such as sound and light effects are assessed as creation in arts design.

3. METHOD

The study started from the following premises: (a) the arts experts who acted as raters would evaluate complex PowerTech works and (b) the assessors had carried out PowerTech projects before. After participating in the revision of the checklist, and attending moderation discussions after each assessment, we checked whether the assessors achieved consistent results in their inter-evaluations via an analysis using Kendall's inter-rater reliability.

3.1. Procedure

This study borrowed from the Delphi technique, whereby a group of experts inform the development of a product such as a clinical guideline (Mckenna, 2011) or in this case a checklist development. Typically, the Delphi technique involves multiple rounds of questionnaires delivered to the expert group, where the focus is on developing consensus amongst a group of experts by taking advantage of their collective intelligence, and the use of at least 2 rounds with feedback between rounds (Kezar & Maxey, 2016). In this study, the Delphi method, using an iterative process and drawing on the feedback of 8 experts and three rounds of questionnaires, to develop a checklist for assessing the Arts of miniature robots in a STEAM contest.

(i) Delphi methods: Round 1

Referring to the Barlex (2004) theoretical background, literature review and the STEAM competition requirements, the 8 responding experts (100%) agreed the checklist within the following five dimensions: (1) aesthetics, (2) design material, (3) artifact performance, (4) bionic, and (5) additional devices. In addition, a total of seven of the 8 responding experts (87.5%) provided qualitative feedback to provide suggestions for improvement and supplement of the checklist.

(ii) Delphi methods: Round 2

Responses from the same 8 experts (100 %) were received. Using the same rubric from Round 1, the experts judged whether the ten items of each index for evaluating arts design are suitable. A total of six of the 8 responding experts (75 %) provided content revised feedback. The feedback was once again analyzed for index content.

(iii) Delphi methods: Round 3

After the revision by Round 2 of Delphi, the Round 3 was to score each index by the same 8 experts (100%). Checklist provided for all questions was combined and coded together. The results of the analysis are indicated some suggestions regarding wording, but no suggestions specific to the content of the modified the checklist. No revisions were made in indexes, as those were previously established as satisfactory in Round 2. Given the high consensus of 100% the usage of checklist to evaluate exemplary miniature robot, it was established that saturation had been reached and no additional rounds were necessary.

3.2. Research setting

The PowerTech Youth Science and Technology Contests aim to improve participants' STEAM learning and problem-solving skills through drawing on the spirit of hands-on STEAM. They are organized by the Taiwan Creative Development Association and the National Taiwan Normal University. In the national contests, participants are requested to make three miniature robots in the morning, and then use them to participate in the competition in the afternoon (relay competitions, tug-of-war competitions, art modeling judging). In the production process, the team must carry out the structural design and production of the mechanical beast according to the designated production theme, and the participants must cooperate to complete the work without the help of parents or teachers so as to avoid the influence of external interference (Hong et al., 2007). The contest is open to elementary and junior high school students who compete in teams of four to six to practice STEAM knowledge together. The primary school teams are made up of five to six students, and their projects include King of Beasts (see Fig.1), whereas the secondary school teams have three to four students and their projects include Crawling Worms (see Fig. 2). The STEAM contest is based on PowerTech activities and can be regarded as a creative and artistic task. To win, participants must implicitly learn related science knowledge, technological knowledge, practical skills, innovative ability, imagination about mechanical design, and problem-solving strategies (Hong et al. 2019). Moreover, the teams are more likely to win if they decorate their miniature robots using artistic and mechanical design ideas for visual appreciation.

Fig. 1. The prototype of King of Beasts

Fig. 2. Arts design on the King of Beasts

prototype

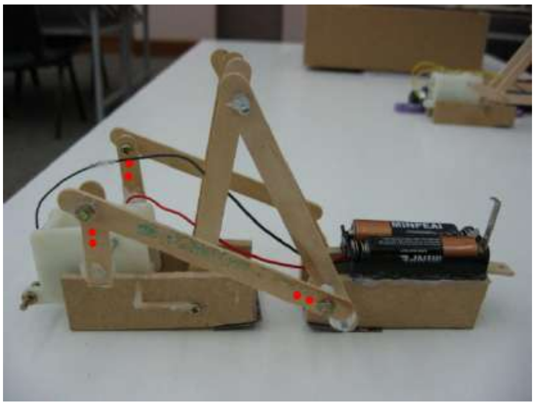

Fig. 3. The prototype of Crawling Worms

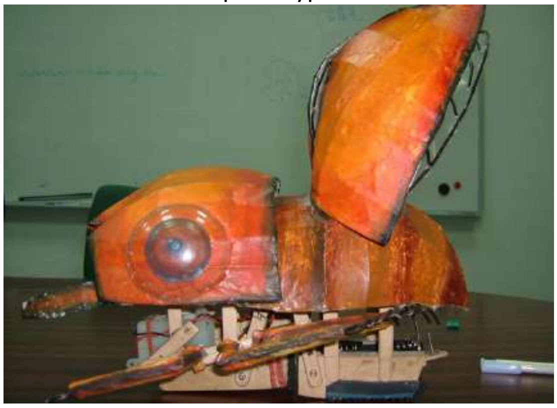

Fig. 4. Arts design on the Crawling Worms prototype

3.3. Experts Panel

Choosing an appropriate expert panel is crucial for success in any Delphi study (Gerrisk & Lathlean, 2015). Purposive sampling was used in this study and a heterogeneous expert panel was sought in order to provide greater diversity of opinion. The expert panel consisted of eight experts from Chinese mainland, the United States, Britain, South Korea, and Taiwan. These eight experts all do research in the field of design and technology education, Arts education measurement and assessment, and STEAM teaching. More than 65% experts have participated in PowerTech contest to review the miniature models' arts design. In an effort to improve response validity, and background was requested. Please see Table 1 for panel member characteristics.

Table 1.
Expert panel members

Number	Nation	Background
1	Chinese mainland	Chinese high school general technology curriculum standards committee
2		
3	United States	A teacher who teaches the American design and technology curriculum
4		A professor of technology and design education
5	Britain	Member of the British Academy of Social Sciences and Professor, a professor of University of the Arts London
6	South Korea	A professor of technology and design education
7	Taiwan	A senior expert in education measurement and assessment
8		A professor of technology and design education

3.4. Stage 1: Checklist construction

There is no set guideline for the number of rounds required in a Delphi study as this is individual to each study (Gerrisk & Lathlean, 2015). The eight experts were invited to review the content validity in more than three rounds of questionnaire followed by a final feedback opportunity via e-mail. They needed to score 30 items' readability and consistency with each dimension from 1 to 5 , where the higher the score, the higher the recognition of the item. Due to the small number of participants, it was simplified to a 3-level scale. The answer were grouped into "Agree" "Not sure" and "Disagree" categories. After receiving the eight experts' comments, the researchers revised the dissenting items and sent them to the experts for review again. This process continued until all experts had no objection to the items; that is to say, the item level index (item-level CVI, I-CVI) was not less than 0.78, and the scale level index (scale-level CVI, S-CVI) was not less than 0.90 (Davis, 1992). The final Arts scale was thus developed. The I-CVI index can be calculated through the number of experts who gave a score of 3 or 4 divided by the total number of experts, and the S-CVI index can be obtained from the average score of all items' I-CVI index.

3.5. Stage 2: Checklist validation: Data analysis

Kendall's coefficient of concordance (W) can be used to compare the degree of concordance of random variables with that of their order statistics (Fuchs & Schmidt, 2021). This study presents an assessment of the interrater reliability of the usability classification system. Consistency is critical to research, as it helps to improve the quality of research by providing the amount of error information about any diagnosis, score, or assessment (Vanbelle, 2016). Kendall's W test can be interpreted as a "harmony coefficient" which measures the consistency between evaluators. Each observation is a judge (or grader), and each variable is the item (or person) being examined. After institutional review board approval was obtained, eight experts participated in this PowerTech STEAM contest via live-streaming and observed students' Arts process. Interrater reliability was calculated and reported using Kendall's W.

4. RESULTS

4.1. The evaluation index of Arts design

Based on the above research design and the first Delphi round of the experts' suggestions, the index of the arts design evaluation was generated by eight experts in Arts design and technology education for further classification. After the second and third Delphi round of the experts' suggestions, eventually the five elements, 10 items (two for each element) and the conceptual description were derived as the tool for Arts design evaluation used for the PowerTech contest (shown in Table 2).

(i) Aesthetics: Tempered color, body shape, and symmetry, in order to have visual aesthetics.
(ii) Design Material: Make use of waste or daily used material, study the properties of these materials in order to make the assembly, and reuse the materials in an effective and economical manner. The lower the cost, the better it will be.
(iii) Artifact Performance: Perfect connections and constructions, fine handiwork which balances the arts design and the movement of the artifact.
(iv) Bionic: Imitates the likeness shape and liveliness model, in order to create a sense of reality.
(v) Additional devices: Added performance, functions, and unique ideas, in order to have a distinctive feature.

Table 2.
Description of scales and indexes for evaluating Arts design

Scale	Requirement	Index	Description
Aesthetics	Aesthetics (visual appreciation)	Color	In harmony with color, colorful
		Symmetry	Adaptable scale of shape, symmetry, and harmony
Design Material	Optimum design	Eco-material	Eco-material, cheaper material
		Material property	Amplify the characteristic of materials for multiple use
Artifact Performance	Design dexterity	Sophisticated design	Assemble perfectly with manual dexterity
		Moving bionic	Moving without bottle-neck
Bionic	Characteristics	Likeness	Outlook imitation
		Liveliness	The movement could show the characteristics of the designated animal
Additional devices	Unique	Added-value functions	Adding functions e.g. an auto-timer into some base.
		Extra functions	e.g. sound or light effects

4.2. The validation of the Arts design checklist

We then analyzed data with frequency distributions of the five scales (aesthetic, material usage, bionic, performance, additional devices), and of each sub-index (color, symmetry, eco-material, material property, likeness, liveliness, sophistication, moving bionic, added function, extra function). The distributions of aesthetics, material usage, bionic, performance and additional devices, and the correlation among these five aspects were calculated. The correlation among these five aspects in form evaluation were analyzed and discussed as well.

According to the expert validation which found consensus on the checklist, Arts design was divided into 10 dimensions. All questionnaire items were designed in the form of a 3-point Likert scale (i.e., ranging from 1 indicating strongly disagree to 3 indicating strongly agree) corresponding to each dimension. The questionnaire items were revised after full integration, and expert ease-of-use verification was conducted by eight experts. As Table 3 shows, the results were as follows: color (M = 2.250, SD = 2.167), symmetry (M = 2.042, SD = 2.000), eco-material (M = 2.146, SD = 2.167), material property (M = 2.146, SD = 2.167), likeness (M = 2.111, SD = 2.222), liveliness (M = 2.134, SD = 2.185), sophisticated design (M = 2.130, SD = 2.191), moving bionic (M = 2.125, SD = 2.200), added-value functions (M = 2.130, SD = 2.192), and extra functions (M = 2.129, SD = 2.194). These descriptive presumptive values indicate that students were highly rated for their Arts design in the STEAM contest.

Kendall’s W is a statistical technique used to measure the consistency of experts' scores. It treats each expert as a group, so the consistency test can also be interpreted as an inter-group significance test (Olawumi & Chan, 2018; Zhang & Cheng, 2020). It is the most commonly used statistical method for this purpose, where Kendall’s W > 0.6 is good, > 0.7 represents excellent, and > 0.8 represents excellent (Viera & Garrett, 2005). Therefore, Kendall’s W was used for consistency analysis of the Arts design of the miniature robots. In the experts’ view, the values for the students' Arts design in the 10 dimensions were as follows: in the color part, Kendall's W is 0.568, *p < 0.5; in the symmetry part, Kendall's W is 0.681, **p < 0.01; in the eco-material part, Kendall's W is 0.571, *p < 0.5; in the material property part, Kendall's W is 0.599,**p < 0.01; in the likeness part, Kendall's W is 0.431, *p < 0.5; in the liveliness part, Kendall's W is 0.665, **p < 0.01; in the sophisticated design part, Kendall's W is 0.511, *p < 0.5; in the moving bionic part, Kendall's W is 0.400, *p < 0.5; in the added-value functions part, Kendall's W is 0.857,***p < 0.001; and in the extra functions part, Kendall's W is 0.625, **p < 0.01.

Table 3.
Kendall’s consistency coefficient verification statistics

Constructs	*N*	*M*	*SD*	Kendall's W	Chi-square	*DF*	*p*
Color	8	2.250	2.167	0.568	9.083	2	0.011*
Symmetry	8	2.042	2.000	0.681	10.889	2	0.004**
Eco-material	8	2.146	2.167	0.571	8.000	2	0.018*
Material property	8	2.146	2.167	0.599	9.579	2	0.008**
Likeness	8	2.111	2.222	0.431	6.897	2	0.032*
Liveliness	8	2.134	2.185	0.665	10.640	2	0.005**

Sophisticated design	8	2.130	2.191	0.551	8.824	2	0.012*
Moving bionic	8	2.125	2.200	0.400	6.400	2	0.041*
Added-value functions	8	2.130	2.192	0.857	13.714	2	0.001***
Extra functions	8	2.129	2.194	0.625	10.000	2	0.007**

5. DISCUSSION

PowerTech is a type of highly competitive STEAM contest that requires students to produce three models in the morning and then use them to compete in relay races and a tug-of-war contest in the afternoon. However, until now there has been no unified Arts design evaluation standard for miniature robots in a STEAM contest. Therefore, this study turned its attention to developing an Arts design checklist with high reliability and good validity, which could be used to measure and assess Arts design for evaluating miniature robots in STEAM contests. Considering the dimension of Arts design highlighted by Barlex's (2004) study, this study referred the "Performance Competence Evaluation Measure" (Krasnow & Chatfield, 2009), and a framework of evaluating humanoid robots driven by aesthetics and motions (Peng et al., 2021), this checklist for assessing the Arts design of miniature robots in a STEAM contest and the items were compiled and refined according to the consensus in each dimension of expert validation.

In order to measure the Arts design fairly and effectively, five evaluation aspects were defined in this study: aesthetics, material usage, bionic, performance, and additional devices. Each of these five aspects are composed of two sub-indices, giving color, symmetry, eco-material, material property, likeness, liveliness, sophistication, moving bionic, added function, and extra function. In the PowerTech contest, eight domain experts attached teams' art making and reviewed rounds of the questionnaire based on these 10 elements and the statistical analysis that was conducted. The process of Arts design checklist is worth further study considering this result to determine whether the checklist has reliability and usability in practice.

6. CONCLUSION

6.1. Conclusions and Implications

Moreover, checklist can develop an awareness of what counts when working with multiple modes and can increase student engagement in an event (Anderson & Kachorsky, 2019). This research developed the index of Arts design evaluation which encompassed five major aspects and 10 criteria for arts design evaluation. It was applied to a miniature robot design in a technological contest involving K4 to K8 students (from 8 to 14 years old). As the PowerTech competition is a research setting, participants designed miniature robots in teams and their designs were evaluated by domain experts, with arts design accounting for 20% of the total score. In line with this evaluative scheme, the checklist of Arts design is very essential to provoke participants to engage Arts design while they worked on miniature robot design.

The study leverages five evaluation aspects and 10 sub-indexes to develop a comprehensive checklist of Arts design in a STEAM contest. These findings significantly enhance the understanding of the Arts design in a STEAM contest and provide an important step toward mapping normative trajectories of both STEAM contest evaluation aspects and Arts design development. Moreover, using the checklist for assessing the art design of miniature models in a STEAM contest could help other researchers and technology teachers think about how to better interpret the conceptions of Arts design.

Furthermore, the consensus needs to be pointed out that although the PowerTech contest of producing miniature robots integrates several elements of STEAM education, the "Arts" would not play the most central role in such rather advanced project, because in the process of making miniature models, Arts is the last procedure and its design will increase the weight and balance of model moving. However, there are many STEAM contests have been organized in current school settings, the checklist of art design of this study may be applied to other STEAM contests similar to PowerTech.

6.2. Limitations and Future Studies

The study suggests that the expert validation found consensus on the checklist and this indicates validity in a STEM contest. However, it would be worth further study to determine whether the checklist usefulness in practice for any other contest rather than Power Tech.

Moreover, another limitation is that the results of the study focus on domain international experts from the fields of Arts design and technology education. In addition, the dimensions of the Arts design checklist lack validation by participants in the STEAM contest, which is an omission while conducting research and needs to be tested in the future. Another limitation is the lack of student self-observations and interviews concerning their practices and instructional decisions in a STEAM contest.

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Analysis of Conceptual Structures in the Chapter of 'Structure ＆ Design' in Three Versions of Chinese High School Technology and Engineering Curriculum Textbooks: Based on the Interpretative Structural Modeling Method

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Abstract

Technology textbooks are important teaching resources and instructional materials in technology education, and technology teachers use textbooks to organize their teaching. The core concepts and elements of technology education are usually presented in a certain structure in textbooks. In China, different versions of textbooks are often written on the basis of the same curriculum standard document, and they are organized through different structures despite sharing the same core knowledge and skills content. The structural organization of knowledge in different versions of textbooks reveals different pedagogical ideas, which reflects the characteristics of different versions of textbooks, and teachers can choose to use the ideas they consider most appropriate to organize their teaching. *Interpretative Structural Modeling* (ISM) Method is a modeling method commonly used in system science to analyse the hierarchy and structure of elements within a system, through which core elements extracted from textbooks can be layered and analyzed in terms of their relationships. The purpose of this study is to analyse the knowledge structure of '*Structure ＆ design*' in three versions of Chinese high school technology and engineering curriculum textbooks (*Sujiao* version, *PEP* version and *Dizhi* version) through the ISM method, and to map the hierarchical structure of the core elements in this chapter. Prior to this, the researcher team operationally defined and finalized the core elements in the three textbooks. In the end, the study demonstrated the feasibility and effectiveness of the ISM methodology in the field of content structure analysis of textbooks and was able to give teachers some suggestions when using textbooks for teaching the chapter '*Structure ＆ design*'.

Key Words: Technology and engineering curriculum textbooks,Technology and engineering education in China, Interpretative structural modeling method, Elementary structure, Structure ＆ design

1. INTRODUCTION

Under China's current education system, the curriculum that students are required to take is carried out in accordance with a unified curriculum programme and curriculum standards, while for front-line teachers, the main basis for classroom teaching is the textbooks that have been developed in accordance with the curriculum standards and reviewed by the government. Within this framework, technical textbooks serve as a bridge between experts in technical curriculum content development and technical teachers. As a major component of China's technology and engineering education, the current curriculum standards document for China's high school '*General Technology*' programme is '*The General Technology Curriculum Standards for General High Schools*', which was written in 2017 and revised in 2020. The standard emphasizes the cultivation of students' core literacy in technical subjects, and puts forward requirements for the preparation of teaching materials for the general technology course, proposing that teaching materials should '*take full account of the knowledge structure of senior secondary school students*', and that '*teaching should be carried out in a planned, organized and hierarchical manner*'.As a result, research on general technology textbooks accounts for a significant portion of K-12 technology and engineering education research in China

1.1. Functions of textbooks

As mentioned above, textbooks both embody advanced educational concepts, fulfil the requirements of curriculum standards and inspire teaching practices. In order to implement the educational concepts of the new curriculum, to help achieve the curriculum objectives and to promote the smooth implementation of the curriculum reform, the writers of textbooks need to present their intentions fully in the textbooks and to help teachers and students to sort out the structural system of the textbooks. Technical textbooks show students the basic knowledge and basic skills of technical subjects. As the main basis for teachers to teach, textbooks largely influence teachers' design of the teaching process. This, in turn, affects the achievement of curriculum objectives and the development of students' technical and engineering literacy. Therefore, analyzing textbooks is important for teachers to use the optimal pathway to achieve classroom teaching and learning activities.

1.2. Textbook construction in K-12 technology and engineering curriculum

In China, technology and engineering education at the upper secondary level relies mainly on the general technology programme, while at the lower secondary level it is mainly integrated into the science curriculum. In addition, China has IT and digital technology programmes from primary to high school. As of now, research on K-12 technology and engineering teaching materials in China mainly includes: introduction to the writing, revision and construction of general technology teaching materials in countries around the world, including China, comparison of multiple versions of technology and engineering teaching materials, and development of school-based teaching materials for technology and engineering, and so on.

And looking around the world. In terms of research on technology and engineering textbooks, global research includes studies on the development of digital engineering textbooks, evaluation and selection of textbooks, student participation in textbook development, and research focusing on the integration of STEM concepts in various types of textbooks.

1.3. The significance of the study of textbook structure

'Structure' refers to the overall form of the interrelationships and interactions of the components of a system according to a certain pattern. Studying the structure of things helps to understand the nature of things deeply. As a complete system, it is necessary to study the structure of textbooks. As the representative individual of cognitive structure *Jerome Seymour Bruner* said, 'Every subject has its own structure, and because of structure, things have simplicity, so that we can understand the inner meaning of things', the structure is the basic framework of knowledge, with structural textbooks are easier for students to understand, and can be preserved for a long time after learning, and not easy to forget. The principles learned by students from the knowledge structure of textbooks can lead to positive transfer of learning in similar learning situations in the future. In addition, structured textbooks are more conducive to the development of students' cognitive networks, which are also structured.

2. METHODOLOGY

The analysis employs both quantitative and qualitative research methods to collect data from high school general technology textbooks for analysis using the ISM method, and to construct a structural model of the core elements.

2.1. Sample

The new version of high school general technology textbooks in China has been in use across the country since autumn 2019. There are five versions of general technology textbooks currently in circulation, of which those published by Jiangsu Phoenix Education Press (*Sujiao version*) have the widest scope of application and are put into use in more than 10 provinces and cities across China, including Jiangsu, Zhejiang and Hainan; those by People's Education Press (*PEP version*) are mainly used in the economically developed city of Shanghai; and those by Geological Press (*Dizhi version*) are mainly used in Henan and other central and western provinces of China are commonly used. As a compulsory course for all high school students after China's curriculum reform in 2017, and as the foundation for the development of high school students' technological literacy. Each version of the textbook has a compulsory section (including '*Technology and Design I*' & '*Technology and Design II*'), in which '*Technology and Design II*' is organized in terms of four broad concepts: structure, process, control and system. For this study, we have selected the chapter *'Structure & Design'* from '*Technology and Design II*' booklet of the three versions of the general technology textbook mentioned above. The Sujiao version and the Dizhi version of the textbooks also won the inaugural award given by the Government of the People's Republic of China.The basic information and the columns of the three versions of the textbooks are shown in Table 1.

Table 1.
Basic information of the three versions of textbooks

Basic information	*Version*		
	Sujiao Version	*PEP Version*	*Dizhi Version*
Published date	*June 2019*	*July 2017*	*August 2019*
Editor in chief	*Jianjun Gu*	*Junhao Chu*	*Lingling Chen and Yongfeng Wang*
Column Setting	*Learning Objectives, Walk-in Scenarios, Tasks, Technology Experiences, Technology Experiments, Technology Investigations, Immediate Actions, etc.*	*Learning Objectives, Discussions & Exchanges, Cases, Out-of-class Practices, Design & Operations, Reflections & Exercises, etc.*	*Preschool Salon, Technology Exploration, Technology Practice, Eye Opener, Creative Workshop, Reading Materials, etc.*
Awards	*Second-class prize of National Excellent Teaching Material*	——	*Second-class prize of National Excellent Teaching Material*

The theme of Technology and Design I	*Technology and its nature* *Technology design process* *Process and programme realization* *Technical communication and evaluation*
The theme of Technology and Design II	*Structure & Design* *Process & Design* *Control & Design* *Systems & Design*

2.2. Research methods

The ISM method is a structural modelling technique that was first proposed by *John N. Warfield* for analyzing sociological problem methods and is now widely used in various fields. Since the method has proved to be suitable for goal analysis as well as textbook development, scholars of education in various countries have actively explored the application of the Interpretative Structural Modelling approach to textbook analysis. The use of the ISM method for textbook analysis and design adopts a systems thinking approach, a view in which the textbook is seen as a teaching and learning system and a resource system. There are several main steps in analyzing textbooks using the ISM method:

(i) Extraction of elements: The researcher needs to analyse the textbook and extract the core constituent elements from it after determining the operational definition based on his/her own practical experience as well as professional knowledge. The extracted core elements are numbered.

(ii) Determine the formative relationships among the elements: In this section, the researcher compares the various logical relationships between the extracted core elements and determines the formative relationships between them based on his or her practical experience and subject knowledge.

(iii) Construct the hierarchical structure relationship diagram: The hierarchical structure relationship diagram shows the hierarchical relationship between the core elements in the textbook. The formation relationship between each element is expressed in the form of a matrix to obtain the *adjacency matrix*. Then the *reachability matrix* is found according to the specific algorithm. On this basis, with a certain hierarchical arrangement algorithm, the hierarchy of each element is decided, from which the formation relationship diagram is made.

(iv) Discussion: For the produced hierarchical structure of the relationship diagram, on the basis of this discussion, and finally determine the hierarchical structure of the relationship diagram.

2.3. Research design

After clarifying the object of study and the research methodology, our research team tried to extract the core constituent elements from the relevant chapters of the three textbooks. This step was carried out using a back-to-back coding model, in which two researchers (a high school teacher and a doctoral student) individually coded and then face-to-face discussion to identify the final core constituent elements.

In turn, the two researchers identified the formative relationships between the elements in the same way and finally obtained the adjacency matrix as required by the ISM method. The researchers then designed a Python-based algorithm to derive the corresponding reachability matrix and the hierarchy of each element. And based on this, a hierarchy relationship diagram was made.

Finally, the researchers discussion and fine-tuned the made relationship diagram and got the final version.

3. IMPLEMENTATION AND RESULTS

3.1. Research process

3.1.1. Operational definition

Before analysing the three versions of the textbook using the ISM method, we first needed to operationally define the core elements to prevent any inconsistency in the extraction of the core elements of the three versions of the textbook. We also adopted a back-to-back extraction method with two researchers to minimise the problem of subjective bias due to the researcher's view of the textbook, teaching experience, and understanding of knowledge. Specifically, we believe that the core elements in a general technology textbook should include the following components:

- Noun concepts or phrases appearing in chapter headings and level headings (if repeated, some consolidation of concepts).
- Concepts covered in the text that are bolded or labelled in a special form, or conceptual content that is clearly explained.

- Some important practical activities (including technology experiments, technology experiences, technology practices, etc., especially those that will have some impact on subsequent teaching and learning).
- Repeatedly occurring in a certain paragraph of text (or the summary of a longer content).
- Given in the summary section after a chapter.

It is worth noting that the above operational definitions have been refined in our extraction practice.

3.1.2. Element extraction
Based on this, we extracted the core elements for the core elements, and finally, in addition to the 26 elements extracted in the PEP version of the textbook, 27 core elements were extracted from both the Sujiao version and Dizhi version of the textbook, which are shown in Table 2.

Among the core elements extracted from the three versions of the textbook, there are some common elements, such as structure, solid structure, frame structure, shell structure, strength of the structure, stability of the structure, etc.. But there are also some special core elements, such as the loads mentioned in the Dizhi version, the combined structure of the Sujiao version, and so on. The three versions of the textbook also differ greatly in their choice of practical content, a point that will be developed in the subsequent analyses.

3.1.3. Mapping the hierarchy
And then, we by determined the formative relationship between different concepts and constructed the adjacency matrix based on it. According to the formula of the reachable matrix, we obtained it by constant iterative operations on the adjacency matrix, and this step was implemented based on Python code. Through the intersection budget of the adjacency matrix and the reachability matrix, we finally determined the division of the core elements. And then we drew the hierarchical relationship diagram according to the operational guidelines of the ISM method with some embellishment, as shown in Figure 1.

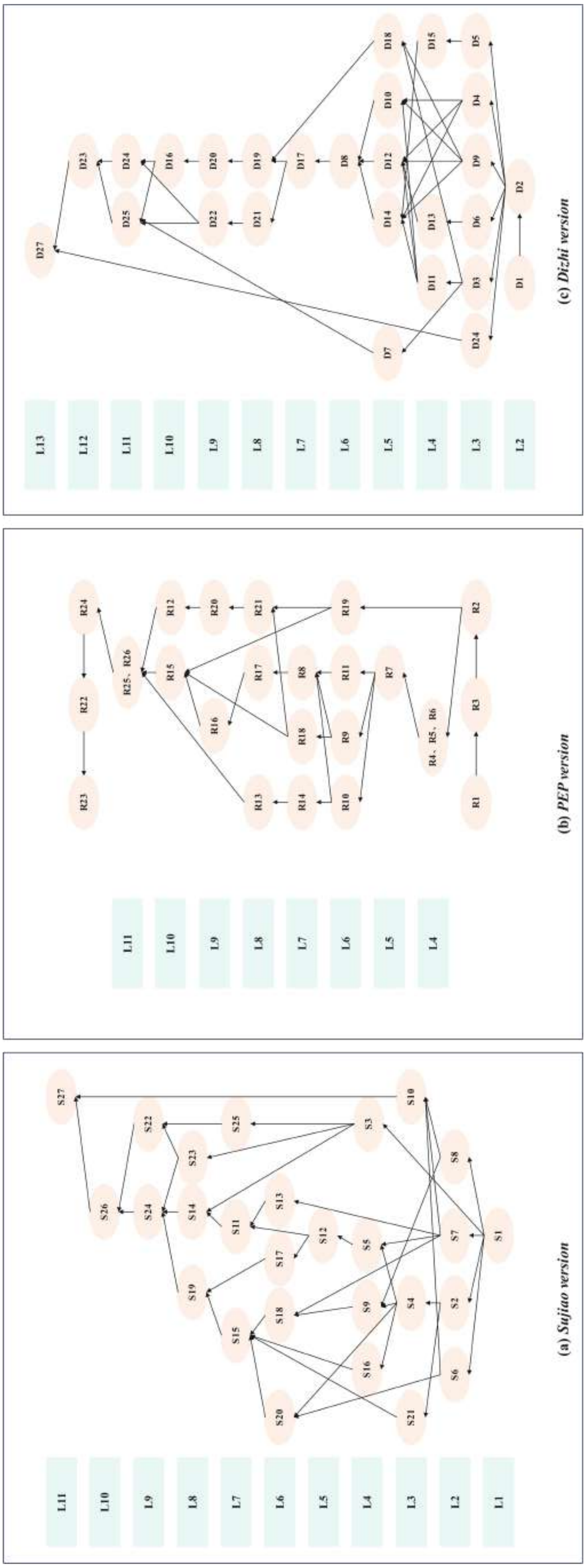
3.2. Analysis of the results

3.2.1. Sujiao version
Compared with the other two versions, the Sujiao version of the textbook has a more networked structure of core content and more diversified main lines. Teachers can draw on these ideas so as to achieve better teaching results. For example, in the teaching of this chapter, in addition to the traditional knowledge structure, we can also teach with the help of the practice line (S1-S7-S5-S12-S17-S19) with the theme of ‘cantilever’.The diversified structural paths give teachers diverse forms of teaching organization and provide conditions for students to learn independently according to their own interests and circumstances, reflecting the concept of student-centred textbooks.

Table 2.
Core elements extracted from three versions of textbooks

Sujiao version	***PEP version***	***Dizhi version***
S1 Structure and their perception S2 Components S3 Significance of structure S4 Forces and deformations of structure S5 Forces in hanging basket bonsai support frames S6 Solid structure S7 Frame structure S8 Shell structure S9 Force analysis of cantilever structure S10 Combined structure S11 Stability of structure S12 Stability of cantilever structure S13 Stability tests on desks S14 Factors affecting the stability of structure S15 Strength of structure S16 Stress S17 Strength of cantilever structure models S18 Shape and strength of structure S19 Strength and cross-sectional shape of cantilevers S20 Materials and strength of structure S21 Connections and strength of structure S22 Realization of structural function S23 Relationship between structure and function S24 Reliability S25 Appreciation of Classical structure S26 Design of structure S27 Design and Fabrication of Standing Desks	*R1 Structure R2 Case of structure and composition R3 Resistance of an egg shell to external forces R4 Frame structure R5 Shell structure R6 Solid structure R7 Forces and Deformations R8 Forces and Deformations in Typical structure R9 Forces and Deformations of Beams R10 Forces and Deformations of Triangular Trusses R11 Forces and Deformations of Arc Arches R12 Functions of structure R13 Stability of structure R14 Factors affecting the stability of structure R15 Strength of structure R16 Shape and strength R17 Cross-section shape and member force deformation R18 Material and strength R19 Connections and strength R20 Structure affecting function R21 Functions of Multifunctional Herringbone Ladders R22 Design of structure R23 Design of a man-ladder model R24 Appreciation of structure R25 Appreciation of natural structure R26 Appreciation of architectural structure*	*D1 structure D2 Structural cases D3 Components D4 Solid structure D5 Frame structure D6 Shell structure D7 Other structural types D8 Structural analysis D9 Structural force analysis and deformation D10 Structural Analysis of Single Bar D11 Loads D12 Structural Analysis of Scaffold Roof Frames D13 Arch structure D14 Structural analysis of steel box girder bridges D15 Steel box girders D16 Strength and Stability of structure D17 Technical Testing and Process Evaluation of structure D18 Stresses D19 Strength D20 Factors affecting the strength of structure D21 Stable structure D22 Factors affecting the stability of structure D23 Structural design and fabrication D24 Wall-mounted simple coat rack prototyping D25 Structural design of a model swing D26 Appreciation of typical structure D27 Evaluation of structural design*

Figure 1.
The hierarchical structural diagram of core elements in three versions of textbooks



3.2.2. PEP version

The overall design of the saddleback profile structure is used in the PEP textbook.The design starts linearly with core elements such as structure, diverges into a network of relationships in the middle, and then wraps up with a practical activity (Design of a man-ladder model). The advantage of this design is that students can apply all the knowledge they have learnt in the chapter at the back of the chapter, so that they can apply what they have learnt and do what they have learnt. Overall, in the chapter on structures, thanks to the relatively small amount of knowledge, the textbook of the Hanyue version is the most logical and neat among the three versions of the textbook.

3.2.3. Dizhi version

In comparison, the Dizhi version of the textbook is not as friendly to students' independent learning as the other two versions.This is reflected, on the one hand, in its greater difficulty (e.g. trying to get students to analyse loading situations in different scenarios) and more content (e.g. concepts outside the curriculum standards such as torque, neutral layer, etc.). On the other hand, there are some inversions in the order of knowledge and presentation (e.g. the concept of structural force analysis is very much at the forefront, but students need to analyse three examples of structures before they can grasp the specifics of this concept). In general, the Dizhi version of the textbook needs more effort from teachers to design clever teaching to reduce the cognitive burden of students.

4. DISCUSSION

Overall, the three versions of textbooks analysed in this study have different characteristics in terms of structural set-up and there are no clear advantages or disadvantages between them.The key is that teachers need to organise and apply them using appropriate teaching tools.

The study suggests that high school technology teachers should firstly sort out the overall knowledge of the chapter, focus on the logic and progression of knowledge, and then organise their teaching activities in a better way in the daily teaching process.

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Practical strategies for strengthening engineering education in the teaching of general technology courses

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Abstract:

Strengthening engineering education in general technology courses can not only enrich the connotation of the original technology courses but also promote the transformation of teaching methods and talent training models. Starting from the existing course content and foundation of general technology, focusing on engineering enlightenment and engineering thinking cultivation in compulsory courses, and implementing engineering themes in selective compulsory and elective courses, drawing on the CDIO engineering education model and based on promoting the implementation of engineering education in classroom teaching, this paper proposes three teaching practice strategies: "strengthening real situations", "strengthening teaching practice in weak links of engineering", and "promoting engineering modeling, analysis and design", providing references for engineering education researchers and practitioners.

Keywords: general technology; engineering education; strategy

At present, engineering education in primary and secondary schools is in the process of initial development. More and more teachers recognize that engineering education is an important way to promote technological innovation, and more and more teachers begin to integrate engineering education into teaching. Primary school science has the content of technology and engineering modules. The production labor content in junior high school labor courses is often easily integrated with engineering education. The high school general technology curriculum system has an inherent engineering gene. There are corresponding technology and engineering series and theme areas for implementing engineering education in the curriculum system. However, in the process of engineering education practice, there are always various confusions and challenges. Taking the practice of integrating engineering education into high school general technology courses as an example, the confusions of many teachers are concentrated on: How can the compulsory module reflect the flavor of engineering? When product projects are transformed into engineering projects, what about the previous projects? Can it be done by increasing the difficulty? Or find new engineering projects? Engineering projects are relatively large projects. What should be done for students with different foundations? And so on. Therefore, taking general technology courses as an example, this article discusses how to strengthen engineering education in teaching in order to integrate with technical courses, enrich the curriculum connotation, and provide practical references for carrying out technology and engineering education in the basic education stage.

1. THOUGHTS ON STRENGTHENING ENGINEERING EDUCATION IN GENERAL TECHNOLOGY TEACHING

After decades of practical accumulation, general technology courses have accumulated rich curriculum resources, teaching cases, and practical projects. These are all the basis for us to carry out engineering education practices. Engineering education is not targeted at cultivating engineers, and engineering thinking is not the patent of engineers. It affects the essential ability of every student to "want to do things, be able to do things, and accomplish things." High school general technology courses are basic courses, not professional or vocational courses. Technology is the basis for completing engineering. Without technology, engineering cannot be done. Not all projects are changed into engineering projects. Engineering education at the high school stage is more about the training of thinking and processes. The systematic view of engineering cognitive characteristics is not just the implementation of engineering content. However, whether it is a technical project or an engineering project, students must have a sense of participation, value, and development. This is the starting point for us to make teaching improvements and prepare for transformation.

1.1. CDIO engineering education model

The CDIO engineering education model refers to Conceive, Design, Implement, and Operate, spanning the entire life cycle from product research and development to product operation. Such a teaching model coincides with the general technology design and production process. The conception stage includes clarifying user needs, considering limiting factors, and continuously improving plans; the design stage includes formulating plans, generating drawings and design schemes, etc.; the implementation stage includes the process of using tools and equipment to turn design schemes into products. Operation includes product maintenance, optimization and elimination. The essence of engineering is creating things. The conception and operation links in the engineering education model are often easily overlooked in actual teaching. Compared with other links, they receive less attention. This is exactly the content that needs to be targeted and strengthened in teaching.

1.2. Conception of strengthening engineering education in general technology teaching

1.2.1 .Enlightenment of engineering education in compulsory modules

Compulsory modules are the main content of academic proficiency tests and college entrance examinations. In class, the "guaranteed minimum" teaching content must be ensured. These teaching contents are the core content. The "guaranteed minimum" content must have basic "guaranteed minimum" teaching activities, problem designs, etc. Put an end to one-sided lectures and spoon-feeding, and put an end to turning work production into handicraft classes. From teaching content in the knowledge dimension to teaching content in the literacy dimension, the teaching method adopted is the practice of teachers' "no upper limit" teaching wisdom. For example, infiltrate some cases on the connotation and relationship between technology and engineering in the compulsory module content, pay attention to the infiltration of relevant content of design thinking, open up computer-aided design content, and have a practical process of optimizing and iterating design schemes. In the process of scheme implementation, pay attention to and guide students to be able to carry out management planning of time, cost, and quality before practice, be able to take tools and materials as needed, operate safely and in accordance with regulations. After practice, organize and store used tools and clean the operating table. Be able to express how one invests in model or prototype production, pursues excellence in craftsmanship, patiently handles details, and continuously pursues breakthroughs and innovations. Experience the unique role of craftsmanship spirit on the quality of technical works, and form a sense of norms, quality consciousness, economic consciousness, environmental protection consciousness, and ethical consciousness related to technology. Through practical activities, cultivate their understanding of engineering design. In project-based learning, guide students to deeply experience the charm of engineering, and at the same time imperceptibly enhance their recognition of engineers. Many contents of compulsory modules can be very naturally integrated into engineering education.

1.2.2. Cultivation of engineering thinking in compulsory modules

Middle school stage is a critical period for cultivating engineering thinking. Engineering thinking is a planning thinking centered on system analysis and comparative weighing. In the process of cultivating engineering thinking, there are various methods and tools. The curriculum standard suggests using methods such as simulation and modeling for design. From the perspective of teaching content, engineering thinking is the comprehensive understanding and application of structure, process, system, and control. The difference from materialization ability lies in that engineering thinking does not emphasize making the model itself, but being able to conduct simple risk assessment and comprehensive decision-making, while paying attention to the thinking habit of cooperation and communication. In current technology and engineering teaching, there are still many problems in the cultivation of engineering thinking. Many teachers pay more attention to the process of innovative design and materialization. They regard students' completion of works as the focus of curriculum cultivation. They do not realize the connection and difference between engineering thinking and design and materialization. Completing model design and production does not represent the effective cultivation of engineering thinking. Engineering thinking is often internal rather than explicit, which leads many teachers to not pay attention to the cultivation of engineering thinking in curriculum design. In addition, the evaluation design of engineering thinking is also a problem. What performances of students can reflect the development of engineering thinking? How to design a reasonable evaluation method to pay attention to the development of students' engineering thinking? These are all troubles in actual instructional design. It can be considered to transform the description of academic quality levels into explicit performance indicators for academics, or borrow learning scaffolds and learning tools to externalize thinking behaviors and do a good job in timely feedback adjustment and evaluation of teaching.

1.2.3. Deepening of engineering theme content in selective compulsory or elective modules

The engineering themes and contents of selective compulsory and elective modules are more abundant. Helping students master technical disciplinary thinking methods based on different technology applications, understand engineering characteristics and values, experience engineering contents such as engineering design, modeling, decision-making, practice, and management, master certain knowledge and skills proficiently, develop systematic thinking and engineering thinking, cultivate labor attitudes, normative consciousness, efficiency concepts and innovative spirits, etc., pay attention to emerging trends and requirements (such as artificial intelligence, sustainable energy technology, etc.), pay attention to the impact of the realization of technology integration on industrial development and the reflected system view, engineering thinking, cultural connotations, etc., is also a deepening of engineering education. Through the comprehensive application of multidisciplinary knowledge, highlighting scientific inquiry and engineering design in technical courses is helpful for developing engineering thinking and comprehensive literacy.

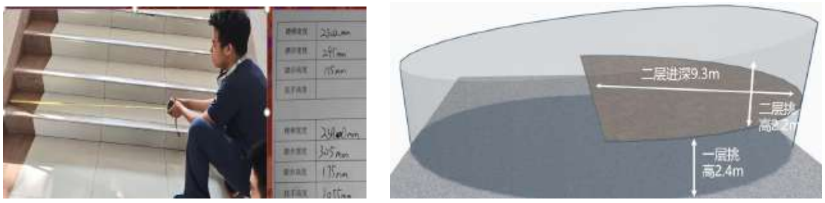
2. Practice and strategies for strengthening engineering education in general technology teaching

Under the background of limited learning time, space, and resources, how can we effectively carry out engineering education? How can we cultivate students' engineering thinking in the classroom? This series of questions are the problems faced in implementing technology and engineering education. Now, taking the teaching practices that have been carried out as an example, this article introduces some practices for strengthening engineering education in general technology courses.

2.1. Strengthen real situations and highlight the flavor of engineering

Select real situations that are suitable for students' lives and where students have equal opportunities for contact. Combined with the characteristics of high school students, we can try to strengthen real situations and highlight the flavor of engineering in some projects on the existing basis. How do we understand the "reality" of a project or task? Especially in strengthening engineering education in general technology disciplines, how do we understand real situations, real engineering projects, engineering design, engineering implementation, and engineering operation and maintenance? The author believes that "reality" not only refers to real life but can also be theoretical reality, transformed reality, virtual reality. As long as it can promote real learning for students. For example, the renovation project of the general technology training base, home decoration projects, school gate renovation projects, etc. From a budget and implementation perspective, the scope is very wide. Another example is existing building models, bridge models, cantilever beam models, miniature theme park landscape design, etc. All can add real situations. Or when carrying out practical project teaching, teachers can lead students to the site to measure, collect, and analyze basic information of engineering projects. Apply engineering design and management ideas to general technology project teaching to make students feel that engineering is not far away and cultivate students' technical awareness and engineering thinking.

For example, the "Transformation of the Science and Innovation Space" project is derived from the previous "Building Model Design and Production" project. Taking one class in the project, "Staircase Design," as an example. In the previous building model project, teaching was through experiencing various teaching aids to design design parameters such as staircase width, step width, height, and railing height that meet ergonomic requirements. Finally, the scheme design was completed. But it raises the question of whether the project situation is real. There are national standards for staircase design. In what situations can staircases be designed by oneself? On this basis, the project strengthened the real situation and was optimized into the need for staircase design for the renovation of the science and innovation center space. Lead students to conduct on-site measurements and complete the scheme design according to real needs. Because the floor where the science and innovation center is located is the science and technology building, the main target group, as well as the theme colors of the ground and walls, the environment outside the building, etc. are relatively complex. Students' design schemes must consider people, the environment, subsequent operations, etc. Weigh and compare multiple factors to obtain the design scheme. Both the project and teaching have been optimized, highlighting the flavor of engineering education.



Students are conducting on-site measurements in the environment

2.2. Based on the CDIO model, strengthen teaching practice in weak links of engineering

On the one hand, the CDIO model focuses on improving knowledge and ability. On the other hand, it focuses on cultivating students' comprehensive ability and engineering concepts. Teachers can apply the CDIO model to actual teaching. On the basis of emphasizing the large process of design and production in general technology courses, they can carry out targeted strengthening design and implementation around the relatively weak conception and operation links in current teaching.

For example, in the conception link of the "Multifunctional Desk Lamp Design and Production" project, teachers focus on cultivating students' multiple perspectives. They can use methods such as brainstorming to conduct divergent thinking around problems from the perspective of user thinking and form multiple design ideas. At the same time, cultivate students' ability to present creativity, that is, be able to express design ideas clearly, explicitly, and vividly in an appropriate form and content. In teaching implementation, teachers can create a situation of "entering the lighting city" to see what elements of actual lamps need to be considered in design. Surrounding the lamps in different exhibition halls of the lighting city, teachers can guide students to correlate the lamps in the exhibition hall with the scenarios of lamps actually used in life. They can also guide students to collect information online to understand the users, usage environments, shapes, usage methods, installation methods, and effects of various lamp types. The analysis of user, usage environment, and object factors is the beginning of design conception. Only when students are clear about the direction of design conception can they better conduct design analysis and smoothly enter the design stage. In the conception stage, pay attention to guiding students to consult relevant materials and conduct field research on relevant markets or products. Teachers are more about helping students control the direction and providing professional guidance opinions, fully reflecting that students, as the leaders, actively participate in project design and production and fully utilize the learned knowledge and relevant materials for project conception.

Look for design clues and strengthen the scheme conception link

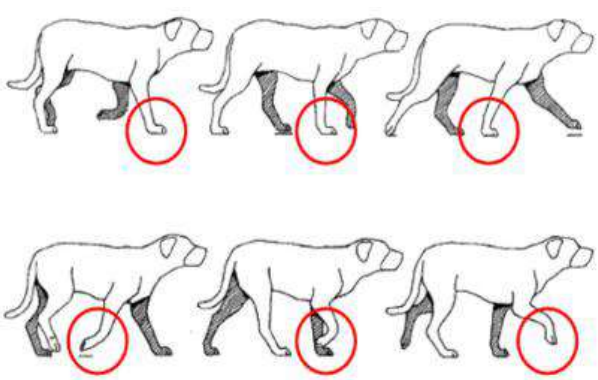
2.3. Focus on engineering thinking and promote engineering modeling analysis and design

Engineering thinking is practical and requires rational system analysis. Students should imagine themselves as an engineer to complete a task. From the perspective of critical thinking, they can discuss technology and engineering issues involving ethical controversies based on evidence, make rational judgments, and be able to draw up a "construction" flowchart based on goals, envision possible problems, and prepare a variety of corresponding solutions in a targeted manner. Consider all aspects and elements of the project more comprehensively, and estimate various factors such as conditions, equipment, resources, equipment, and expenses required in the "construction" process. Engineering is more like a comprehensive solution. In the process of formulating a scheme, it is necessary to consider compliance with scientific and technical principles, and it is necessary to conduct mathematical model calculations and optimizations. Of course, technical tests or model validations are also needed.

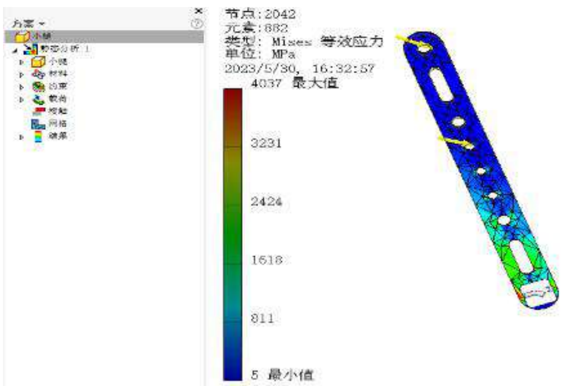
For example, the "Pipe Bell Instrument Design and Production" project is originally a relatively complex project that involves the application of interdisciplinary knowledge in multiple fields such as science and technology, engineering, and humanities, and has rich space for scientific exploration. How to choose materials to make a pipe bell for real performance? What factors are related to the pronunciation frequency of the pipe bell? How to carry out pipe bell production? How to design the bracket structure and a series of real problems need to be solved jointly by teachers and students. For example, in teaching, teachers organize students to conduct percussion experiments with five aluminum alloy pipes of the same pipe diameter and different pipe lengths. While recording the pipe length, they also record the occurrence frequency and relative pitch. It is found that the loudness of noise increases with the increase of pipe length. Teachers and students jointly solve the relationship between factors such as pipe length, sound production, and noise, and form the optimal solution through weighing and comparison to cultivate engineering thinking.

Engineering-oriented "pipe bell instrument"

For another example, in the design stage of the "mechanical dog" project, engineering design software is applied for system analysis and comparative weighing to ensure design quality and improve design efficiency. Taking the design of the mechanical dog's legs as an example, this process covers key links such as motion simulation and stress testing. By observing the change in the movement position of the dog's thigh and calf leg structures, the movement characteristics are quantified as parameters to determine the relationship between the rotation parameters. After that, motion simulation settings are carried out to simulate the movement trajectory of the mechanical dog's legs, discover potential mechanism conflicts or motion interferences in time, and make corrections in the early stage of design. The finite element analysis function in the design software helps students optimize in terms of structural design and material selection. This not only improves design efficiency but also ensures the safety and reliability of the mechanical structure and maximizes cost-effectiveness.



The change in the movement position of the dog's leg structure



Stress analysis results of the calf structure angle

3. SUMMARY

The significance and value of engineering education implementation have gradually received the attention and recognition of teachers. However, in the process of curriculum design and classroom implementation, how to truly implement engineering education is still a difficult problem. Gradually making improvements and optimizations on the basis of the original curriculum is also a realistic move. Let engineering education be oriented to all students, cultivate students to propose solutions to real problems, and try to make engineering decisions in various complex situations. The general technology discipline needs to do a good job in cultivating engineering education at the basic education stage and connect well with higher engineering education in order to provide the country with high-quality engineering talents.

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Physical-chemical oriented science and technology innovation practice: Construction and implementation of the curriculum group of technology and engineering education in primary schools

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Abstract

This paper aims to explore the importance of technology and engineering enlightenment education in primary schools, physical-chemical oriented science and technology innovation practice as the goal orientation. By building primary school engineering and technical literacy curriculum group as the core to explore implementation way, build resources environment, establish evaluation system and form the teacher team. Through the implementation paths above to promote the development of technology and engineering awareness in primary and secondary schools, so as to provide useful reference for researchers in related fields.

Key Words: physical-chemical orientation, science and technology innovation practice, construction of technology and engineering enlightenment education curriculum group

1. PREFACE:

With the development and change of the times, the society needs a large number of talents who master breakthrough technologies and have the ability to solve practical problems. This has led to the country's positive vision for the cultivation of the younger generation in the future. In May 2023, the Ministry of Education and other 18 departments jointly issued by the "A guideline on strengthening the new era of science education of primary and secondary school ", through high-quality, flexible and personalized teaching and learning, students can have broader knowledge such as technology and engineering, and can gradually become future talents with thinking ability, critical ability and skills, so as to make contributions to the society in practical work. After the new round of curriculum reform, engineering education in primary and secondary schools is also taken as an important measure to echo the national innovation-driven development strategy and cultivate innovative talents. In primary school, to better awaken students' engineering and technical learning interest and potential, guide them into the real problem situation to the physical-chemical oriented scientific innovation practice, in teamwork, hands-on practice, positive expression and professional enlightenment, gradually become the center of learning, and better understand the rules of how things work.

2. SPECIFIC CONSTRUCTION AND IMPLEMENTATION:

2.1. Construction of primary school engineering and technology literacy training as the core of the enlightenment education curriculum group.

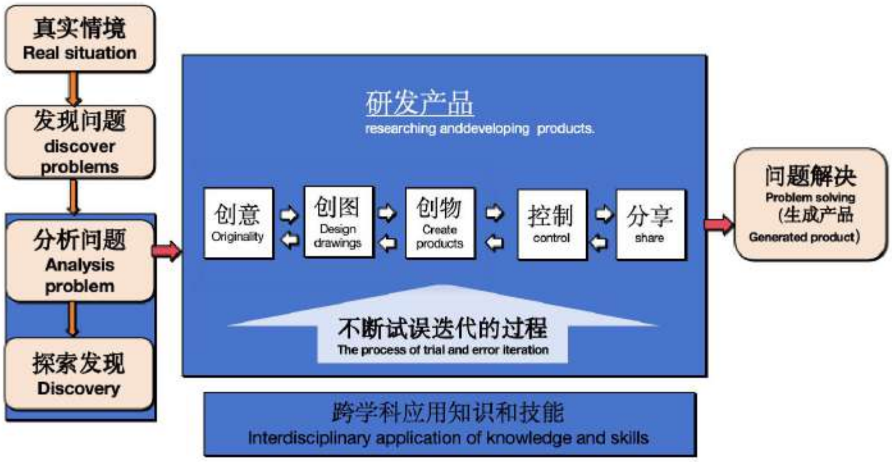
The Compulsory Education Curriculum program (2022 edition) proposes to "optimize the implementation methods and paths of comprehensive practice activities, and promote engineering and technology practice. Actively explore the change of learning environment and way under the background of new technology. " In the construction of primary school curriculum system, engineering and technology enlightenment education should be systematically thought about from the aspects of national curriculum, local curriculum and school science and technology practice activities. **First, the school-based implementation of national science and labor curriculum organically integrates engineering and technical literacy cultivation,** and combs out the content of "technology and engineering" from the current science and labor curriculum textbooks. Construct the serialized engineering practice course from both vertical and horizontal directions. Vertical focus on the spiral progression of engineering elements, forming a cross-year project sequence based on the core concept of "engineering design and materialization"; Horizontal focus on the transfer and application of engineering elements, integration and optimization of existing engineering practices, to form the core concept of "engineering design and materialization" experimental group; At present, the school has developed more than 20 science-themed projects integrated with engineering and technology education, such as "Defending Ice cubes", "Homemade Musical Instruments", "Lighting up dollhouses", "Crazy roller coasters", "Self-made Mars landers" and "Making windmills spin faster". **Second, local curriculum and engineering literacy cultivation are widely combined.** In combination with the characteristics of provincial and local curricula, fully tap the high-quality site resources (venues, colleges, enterprises, etc.), develop a series of engineering and technology enlightenment education projects that meet the experience and practice of students of different years, and carry out interesting penetrative learning through different support methods such as college collaboration and school-enterprise cooperation; **The third is the deep integration of school-based science and innovation courses and engineering literacy cultivation,** from the perspectives of mechanical engineering, aerospace engineering, automotive engineering, energy engineering and other aspects to develop advanced engineering enlightenment courses.

Table 1
Enlightenment education curriculum group (a part)

Course path	grade	Subject name	Big idea	Content learning standards	Curriculum literacy learning standards	instructor
the school-based implementation of national science and labor curriculum organically integrates engineering and technical literacy cultivation	Grade 4	Homemade Musical Instruments	Integration with scientific disciplines: Sound is produced by the vibration of objects.	Changing the properties of an object can make different sounds	Observe the different sounds that common objects can make in life	Science teacher
					Determine the conditions under which musical sounds are produced	
			Integration with Labour curriculum: Design can be improved by disassembly, assembly, design and testing;	Elements and drawings of model design	Able to demonstrate products and describe operation process	
local curriculum and engineering literacy cultivation are widely combined	Grade 5	Automatic irrigation system for smart farm	Modular curriculum portfolios such as Labour, information and technology education: designed to respond to self-identified needs	Programming module system drawing technology	Participate in research to understand design problems	External professional teacher + internal teaching assistant
				Elements and drawings of the technical proposal	Identify realistic needs and determine success standard	
the deep integration of school-based science and innovation courses and engineering literacy cultivation	Grade 6	Aerospace simulation of space capsule planting	Modular curriculum portfolios such as science, information and technology education: designed to respond to self-identified needs	Environmental status and conditions of the capsule	Observe the planting conditions in the simulated space capsule environment	University teachers + school teachers
					Determine the influence of surrounding conditions on planting	

2.2. Explore the implementation of primary school engineering enlightenment education.

Primary school engineering enlightenment education is to strengthen technology and engineering practice in interdisciplinary education. It will be based on real problems, using the comprehensive application of knowledge and skills of various disciplines, modeling, engineering and other ways to present the solution of the problem. Emphasize "learning by doing" and "learning by creating", promote students to understand the value and significance of engineering activities, experience the basic process of engineering design, and cultivate the ability of design thinking, empathy and understanding, cooperation, cost accounting and risk assessment, and open problem solving. Therefore, in the concrete implementation process, school built a project-driven engineering and technology enlightenment learning model. In order to solve practical problems in this model, students adopt the iterative method of "design-development-training-implementation-improve-re-development and perfection", and students need to go through three main processes of "create ideas", "create pictures" and "create things". Teachers design three iterative cycles, in which the inquiry cycle provides scientific basis for the optimal design of the scheme, the test cycle is used for the optimization of the product, and the external cycle is used for the iteration of the learning process of the entire project. The three cycles promote each other and complement each other to help students complete learning activities together.



2.3. Construct the resource environment of school engineering enlightenment education.

Engineering enlightenment education is carried out at the primary school to cultivate students' innovative thinking, practical ability and teamwork spirit. School focuses on the spatial reconstruction of the development of technology and engineering literacy, through open, diverse and composite space design to meet the environmental needs of community learning, so that technology and engineering learning can actually take place, and promote the improvement of students' core abilities. The second is to establish a resource sharing mechanism. Relying on vocational colleges, research institutes, high-tech engineering enterprises, science and technology museums, museums, etc., to cooperate with social forces to build exploration and experience learning space for enlightenment education.

2.4. Establish the evaluation system of engineering enlightenment education curriculum group

The evaluation content of "engineering literacy" is added to the comprehensive quality evaluation of students. Starting from the principle of process evaluation and multiple evaluation, the evaluation of works, learning performance and objective knowledge is carried out first, secondly, through self-evaluation, peer evaluation, teacher evaluation, etc., carry on the multi-angle evaluation.

Table 2-1.
Contents and standards of learning performance evaluation of engineering initiation education courses

	0	1	2	3	4
Identify and understand the problem	No identify the problem	The problem or challenge is not clearly understood or accurately identified	Part of the problem or challenge is identified	Most of the problem is identified	All parts of the problem or challenge are included or identified and clearly understood
Establish a scheme	No scheme	No investigation of the scheme, and no feasibility assessment of the designed scheme;	Part of the scheme is investigated, and the feasibility of part of the scheme is evaluated.	Basically complete the design of the scheme, and make a certain assessment of its feasibility;	Be able to conduct comprehensive investigation and exploration, select suitable schemes after different designs of schemes, and evaluate the feasibility of schemes
Design drawing	No design	The proposed design has no corresponding problem, or no parameters to present the problem. The drawings cover one of the following necessary details: proportions, dimensions, materials, marking	The proposed design corresponds to the problem and presents the parameters of the problem. The drawings cover 2 of the following necessary details: proportions, dimensions, materials, and	The proposed design corresponds to the problem and presents the parameters of the problem. The drawings cover 3 of the following necessary details: proportions, dimensions, materials, and marks	The design drawing is exactly corresponding to the problem, and the parameters of the problem are presented. The drawings are easy to understand and cover all the following details: proportions, dimensions, materials, marking

			marks		
Make a model	No model	The submitted model does not have a corresponding problem or handle any parameters. The model is not built according to the submitted drawings	The submitted model corresponds to the problem, but only handles 1 parameter. The model is not built according to designs or drawings	The submitted model corresponds to the problem, but only handles half of the parameters. The model is built according to the design drawing	The submitted model corresponds to the problem, all the parameters of the problem are derived, and the design is built according to the drawing
Test improvement	No improvement	The collected data is not used to make appropriate changes to the model's design/drawings	The collected data is used to make appropriate changes, but the model design/drawing is not modified at the same time	The collected data is used to make appropriate changes to the model and design/drawing. But not all changes are carefully thought or presented	The collected data is used to make appropriate changes to the model and design/drawing. All changes are carefully thought and presented
Display and communication	No display and communication	The report meets only one of the following criteria: 1. The question is reiterated 2. Demonstrate and/or discuss the steps of the engineering process, and how they are used 3. Presented the collected evidence in a clear and appropriate manner 4. The group discussed the effect of the final product with the evidence they collected	The report meets two of the following criteria: 1. The question is reiterated 2. Demonstrate and/or discuss the steps of the engineering process, and how they are used 3. Presented the collected evidence in a clear and appropriate manner 4. The group discussed the effect of the final product with the evidence they collected	The report meets three of the following criteria: 1. The question is reiterated 2. Demonstrate and/or discuss the steps of the engineering process, and how they are used 3. Presented the collected evidence in a clear and appropriate manner 4. The group discussed the effect of the final product with the evidence they collected	The report meets all of the following criteria: 1. The question is reiterated 2. Demonstrate and/or discuss the steps of the engineering process, and how they are used 3. Presented the collected evidence in a clear and appropriate manner 4. The group discussed the effect of the final product with the evidence they collected
Evaluation reflection	No evaluation reflection	Be able to evaluate one or two elements of the formative gauge and to reflect on a small part of the process or result	Be able to evaluate a small part of the formative gauge and to reflect on a small part of the process or result	Be able to evaluate half of the formative gauge and to reflect on the process or result	Be able to evaluate the formative gauge and to reflect on the process or result

Table 2-2.
Examples of evaluation contents and standards of teacher evaluation, self-evaluation and peer evaluation of engineering initiation education courses

Subject name	Grade	Evaluation subject	Evaluation content and criteria
Automatic irrigation system for smart farm	Grade 5	teacher	What evidence is gathered by team communication and collaboration? What areas might be improved?
		student	Self-reflection, how to achieve goals or evaluate own performance?
		companion	In what areas do peers have the opportunity to provide feedback, and how is the feedback delivered and received?

2.5. Build a team of engineering enlightenment education teachers, and the implementation path

The essence of teacher training in engineering enlightenment education in primary schools is to enhance the professional motivation of teachers with different disciplinary backgrounds, that is, to make efforts to study the "real problems" and "real needs" in the process of cognition and practice of engineering enlightenment education, and establish school-based research and training that integrates "learning" and "research", so as to bring the development of engineering enlightenment education into a normal state and achieve win-win results.

2.5.1. Establish a school-level project research and training community to promote teachers' professional development.
To build a cross-campus project research community, to jointly carry out project research in large units, interdisciplinary, project-based and academic evaluation, and form a research model of "project research-classroom research-special research", improve professional quality and promote the development of discipline teams.

2.5.2 Build a cross-district teacher research and training community to enhance the overall strength of the discipline team.
To build a cross-district teacher research and training community by means of internal linkage and external integration. On the basis of "mirror our school - program analysis - experience first - review exchange - picture of progress - project iteration", cooperate with teachers and experts to jointly carry out training, project cooperation and other activities to promote teachers' teaching exchange and experience sharing.

3. CONCLUSION:

Primary school technology and engineering enlightenment education is not only an important measure to respond to the training of national innovative talents, but also a real action to awaken students' interest and potential in engineering and technology learning in primary school. Therefore, the practice of enlightenment education curriculum group with students as the main body and in line with their cognition and learning rules can stimulate students' interest in engineering technology, enhance engineering literacy, and promote the early training of top innovative talents in the process of material-oriented scientific and technological innovation practice.

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Utilize the ABC Theory of Attitude to Shape the Engineering Attitudes of Primary and Secondary School Students

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Abstract

This study is centered around the theoretical framework of Attitude-Behavior-Cognition (ABC) and aims to explore effective strategies for nurturing engineering attitudes in elementary and middle school students. By incorporating the developmental patterns of students' physical and mental growth, this research delves into critical aspects and challenges in fostering engineering attitudes. A three-dimensional strategy system is proposed, focusing on cognitive, affective, and behavioral intention dimensions. The study includes an in-depth analysis of the current status, implementation strategies, and effectiveness of engineering education in primary and secondary schools in Wuxi City, providing empirical examples and practical experiences to support the cultivation of engineering attitudes among students. Ultimately, the research seeks to enhance engineering education in primary and secondary schools and cultivate future talent in the engineering field.

Keywords: Elementary and Secondary Education, Engineering Attitudes, Strategic Methods, the ABC Theory of Attitude

In the rapidly evolving technological landscape, engineering plays a pivotal role in driving social progress and economic development. The formative years of primary and secondary education are crucial for shaping students' knowledge frameworks, enhancing cognitive skills, and instilling values. In 2023, China's Ministry of Education emphasized the coordinated development of science and engineering education, establishing a strategic framework for engineering education in primary and secondary schools. However, the nascent stage of this initiative underscores the need to prioritize engineering education at these levels, particularly for fostering positive engineering attitudes among students during their developmental years.

1. ATTITUDE THEORY: A FRAMEWORK FOR INFLUENCING ENGINEERING ATTITUDES IN PRIMARY AND SECONDARY EDUCATION

Engineering education at the primary and secondary levels is instrumental in building students' confidence in their engineering abilities, fostering their independence and identity as engineers, and guiding them toward potential engineering careers. Research indicates that many individuals develop an interest in science and engineering during their elementary school years.[i] Introducing engineering concepts to students early in their education can significantly impact their attitudes toward engineering, presenting it as a viable career choice before preconceived notions about the field take root.[ii]

1.1. The Relationship Between Primary and Secondary Students and Engineering Education

Several significant negative factors influence students' attitudes toward engineering education at the primary and secondary levels, necessitating interventions and guidance during this critical developmental stage.Firstly, curiosity. Primary and secondary school students are at the age when they are full of curiosity about the world, they are interested in new things and eager to explore the unknown world. Engineering education can satisfy students' curiosity and stimulate their interest in the field of engineering through vivid and interesting curriculum content, practical activities and science exhibitions. Second, rich imagination. Engineering education can guide students to transform their imagination into actual engineering design and innovative programs, and cultivate their innovative thinking and practical ability. Third, high plasticity. Primary and secondary school years are the key period of students' physical and mental development, and their values, learning habits and ways of thinking are highly plastic.

1.2. Understanding the ABC Model of Attitudes

The ABC model of attitudes comprises three interconnected dimensions: cognitive, affective, and behavioral intention. The cognitive dimension forms the foundation, encompassing an individual's understanding and knowledge of the attitude object, including comprehension of engineering concepts, principles, and applications. The affective dimension captures the emotional responses toward the attitude object, such as interest, enthusiasm, and pride in engineering. The behavioral intention dimension reflects the individual's inclination to engage with the attitude object, demonstrated by their willingness to participate in engineering activities and pursue engineering careers. The interplay among these dimensions plays a pivotal role in shaping an individual's overall attitude.

2. ANALYTICAL FOCUS AND CHALLENGES IN FOSTERING ENGINEERING ATTITUDES AMONG PRIMARY AND SECONDARY SCHOOL STUDENTS

The cultivation of engineering attitudes within primary and secondary education involves the enhancement of students' foundational engineering knowledge, the development of engineering thinking habits, the promotion of interest in engineering careers, and the increase of awareness regarding engineering practices. The U.S. Next Generation Science Education Standards assert that "Elementary and secondary science and engineering education should enable students to recognize the connections and distinctions between science and engineering by understanding the work of scientists and engineers." [iii]Furthermore, this educational framework aims to facilitate a deeper understanding of the intellectual methodologies and conceptual frameworks inherent in both science and engineering, approached from both disciplinary and interdisciplinary perspectives. The overarching goal of this educational strategy is to stimulate students' curiosity and desire for exploration, thereby attracting them to and encouraging sustained engagement in the engineering field.

2.1. Analytical Focus

2.1.1. Cognitive Dimension

In terms of cognitive dimensions, the focus is on guiding primary and secondary school students to understand what engineering education is about and to form a correct understanding through curriculum teaching and activities. First, the construction of a knowledge system. Primary and secondary school students ' understanding of engineering needs to be based on a systematic body of knowledge, including basic concepts, development history, major fields, and technical methods. Second, the cultivation of cognitive methods. For primary and secondary school students, the cultivation of cognitive methods should focus on being interesting and interactive, and stimulate students' interest and enthusiasm through games, competitions, and other forms. At the same time, teachers can also guide students to use information technology, such as the Internet and virtual reality, to broaden their cognitive channels and improve their cognitive efficiency.[iv]

2.1.2. Emotional Dimension

The affective dimension highlights the significance of mobilizing and stimulating positive emotions among students. Primarily, the stimulation of interest is essential; engaging primary and secondary students in engineering represents a critical objective within this dimension. Additionally, enriching emotional experiences is fundamental to the affective dimension. Participation in engineering practice activities, competitions, and club events allows students to experience enjoyment in engineering, a sense of achievement, and the spirit of teamwork. These experiences cultivate a sense of social responsibility and mission, while also emphasizing the appeal and value of engineering. Within the emotional dimension, it is crucial to focus on the primacy effect, utilizing both the primacy effect and the anchoring effect to elicit positive emotions. The primacy effect refers to the fact that people's first impressions of things will affect their subsequent judgments and overall perceptions of things, and have a strong persistence.[v]

2.1.3. Dimension of Behavioral Intention

The dimension of behavioral intention underscores the necessity of encouraging students to actively participate in aspects related to engineering education and career development. Primarily, the cultivation of practical skills is of paramount importance. Practical competence is a critical indicator within the behavioral intention framework, necessitating the enhancement of students' practical abilities and innovative thinking. Additionally, effective guidance in career planning is essential. Career planning constitutes a long-term objective within the behavioral intention dimension. It is vital to assist students in understanding the developmental opportunities and requirements associated with engineering professions. This guidance should aim to facilitate the establishment of accurate career perspectives and values among students, while also motivating them to formulate personal career plans that resonate with their interests and strengths, thereby inspiring them to diligently pursue their academic objectives to realize these plans.

2.2. Challenges

2.2.1. Disparities in Educational Resources

Firstly, significant urban-rural disparities exist within the educational landscape. Schools situated in urban areas generally benefit from a higher number of qualified educators, advanced laboratory facilities, and a more extensive curriculum. These disparities can profoundly affect students' interest in and perceptions of engineering, potentially influencing their future career trajectories. Furthermore, regional disparities are also significant. Educational institutions in economically developed areas often possess the financial resources and human capital necessary to invest in a diverse range of engineering education initiatives.

2.2.2. Challenges in the Innovation of Pedagogical Approaches

The evolution of teaching methodologies requires educators to exhibit a high degree of professionalism and pedagogical expertise, in conjunction with adequate support and resources from educational institutions. However, in practice, teachers frequently face challenges such as excessive workloads and inadequate teaching resources, which impede their capacity to innovate instructional strategies.

2.2.3.The variability among individual students is considerable.
Firstly, there is a notable diversity of interests among students. Some students may favor mechanical engineering, while others may be more inclined towards electrical engineering or bioengineering. Educators must provide tailored learning resources and opportunities for activities that align with students' interests to effectively address their individual learning needs. Secondly, significant differences in cognitive levels are evident. Students across various grades and with differing personalities exhibit considerable variations in their interest in and acceptance of engineering concepts.

2.2.4. Inadequate Hardware and Software Resources
Firstly, there exists a significant deficiency in laboratory equipment. The lack of sufficient laboratory facilities impedes students' capacity to engage in practical engineering experiments and operations, consequently detrimentally impacting their understanding and mastery of engineering principles. Secondly, there is a notable scarcity of teaching resources. Numerous primary and secondary educational institutions are deficient in essential software tools, such as engineering design and simulation software, as well as printed materials, including engineering textbooks and popular science literature. This shortfall restricts the content and pedagogical approaches utilized in instruction. Thirdly, the qualifications of educators are insufficient. At present, the availability of engineering education instructors in primary and secondary schools is limited, with a minimal proportion of teachers possessing specialized training in engineering education. Many educators lack a professional engineering background and practical experience, which hinders the effective delivery of engineering education. Lastly, the curriculum framework is inadequately developed. The majority of engineering education programs in primary and secondary schools lack standardized curriculum guidelines and syllabi, resulting in a curriculum that is neither systematic nor grounded in scientific principles.

2.2.5. The insufficiency of social engagement in engineering education is evident.
Firstly, there is a notable deficiency in social awareness regarding the significance of engineering education, which is frequently regarded as merely an extension of vocational training, with limited integration into foundational education at the primary and secondary levels. Secondly, the participation of enterprises in engineering education is inadequate. As the principal entities responsible for engineering practices, these enterprises demonstrate a lack of incentive to contribute to the engineering education of students in primary and secondary schools. The absence of effective collaborative frameworks restricts students' opportunities to gain practical engineering experience and receive vocational guidance.

3. ATTITUDE RESHAPING: A STRATEGIC INITIATIVE TO INFLUENCE ENGINEERING PERSPECTIVES AMONG PRIMARY AND SECONDARY SCHOOL STUDENTS

3.1. Case Study of Wuxi City

Wuxi City prioritizes engineering education within its primary and secondary school systems. To confront the challenges present in this domain, the city has instituted a comprehensive array of strategies. These strategies encompass the proactive development of curricula, the training of educators, and the establishment of practical training facilities. Furthermore, a wide variety of engineering education courses and hands-on activities have been implemented. This multifaceted strategy not only cultivates engineering mindsets among primary and secondary school students but also provides valuable insights and experiences for other regions to replicate.

3.1.1.The Practical Approach to Engineering Education in Primary and Secondary Schools in Wuxi
3.1.1.1. Curriculum Development

Wuxi City has formulated curriculum standards and syllabi for engineering education in primary and secondary schools, which clearly outline the objectives, content, and methodologies pertinent to engineering education. By these standards and syllabi, individual schools have developed engineering education courses tailored to their specific contexts and characteristics. For example, some schools offer courses in robot programming, while others concentrate on 3D printing or innovations in science and technology.

3.1.1.2. Teacher Training

Wuxi City has assembled a team of both full-time and part-time educators, based on the recruitment of outstanding graduates from prestigious domestic and international universities to serve as full-time instructors in engineering education at the primary and secondary levels. The city has initiated the "Ten Hundred Thousand" program for engineering education teachers, thereby establishing a sustainable framework for enhancing pedagogical competencies among educators. Additionally, Wuxi has created a network of experts dedicated to fostering exceptional engineers within primary and secondary educational institutions. This initiative aims to attract graduates from engineering disciplines, highly skilled engineers, specialized course instructors from higher education institutions, and proficient industry professionals to participate in engineering education. Moreover, Wuxi promotes teacher involvement in engineering education by implementing an effective training framework designed to enhance teaching capabilities. The city also encourages the development of an expert network focused on cultivating exemplary engineers in primary and secondary schools. Concurrently, Wuxi advocates for educators to engage in research related to engineering education, exploring innovative teaching methodologies and approaches suitable for primary and secondary school students.

3.1.1.3 Practice Base Construction in Wuxi

Wuxi has established numerous engineering education practice bases, offering students an abundance of practical opportunities. Notably, the city has initiated the "Double-High Cooperation" program. During the summer, various activities, including the "Engineering Education Summer Camp," "Engineering Experience Camp," "Artificial Intelligence Summer Camp," and "Intelligent Manufacturing Camp," are organized. These activities provide students with a diverse array of options, enabling them to select from a broad spectrum of choices. These endeavors afford students colorful options to conduct engineering experiments, visit enterprises, and engage in interactions with engineers within the practice bases, thereby enhancing their engineering practice and innovation capabilities.

3.1.2.Engineering Attitude Shaping Strategies for Primary and Secondary School Students in Wuxi
3.1.2.1 Cognitive Dimension

Regarding the curriculum, a tiered engineering education program is designed in accordance with the cognitive levels of students across different grades. The curriculum for lower grades emphasizes engineering stories and basic engineering phenomena to stimulate students' curiosity. Conversely, the curriculum for upper grades progressively introduces engineering design and practical content, aiming to improve students' cognitive and practical abilities. Wuxi actively engages in science popularization activities, such as organizing science and technology festivals and lectures, to disseminate engineering knowledge. Leveraging information technology, an online engineering education platform has been established to furnish students with extensive learning resources. Additionally, in conjunction with campus culture, engineering-themed bulletin boards and science popularization display areas have been set up on campus, fostering a strong engineering atmosphere.

3.1.2.2. Emotional Dimension

A spectrum of practical engineering activities has been organized, including the Robotics Challenge for Primary and Secondary School Students and the Science and Technology Innovation Competition. These activities emphasize the cultivation of students' teamwork spirit and innovation abilities, while also stimulating their interest in and affection for engineering. Teachers narrate stories of local engineering achievements and engineers in Wuxi, thereby enhancing students' pride and sense of belonging. Furthermore, engineering-themed cultural activities and speech contests are conducted in conjunction with campus culture, reinforcing students' emotional identification with engineering.

3.1.2.3 Behavioral Intention Dimension

Diverse engineering club activities spanning various fields, such as robot programming, 3D printing design, and environmental engineering, are conducted. These club activities are planned and organized by students themselves, with guidance and support provided by teachers. Students are encouraged to participate in volunteer services, such as community science and technology popularization activities and environmental protection engineering practices. Wuxi also actively collaborates with enterprises to provide students with career experience and internship opportunities, aiding them in understanding the practical demands and development prospects of engineering careers. In conjunction with campus culture, activities such as club showcase events, volunteer service commendation conferences, and career planning competitions are held, stimulating students' enthusiasm and motivation for participation. Furthermore, the implementation of these strategies has also had a ripple effect on the education system in Wuxi. Teachers, who were initially tasked with integrating engineering education into their curricula, have themselves undergone professional development and gained a deeper understanding of engineering principles and methodologies. This, in turn, has enriched their teaching content and made their classrooms more engaging and interactive for students.

Schools in Wuxi have also benefited from the enhanced focus on engineering education. They have seen an improvement in students' overall academic performance, particularly in subjects related to science, technology, engineering, and mathematics (STEM). This is because engineering education encourages critical thinking, problem-solving, and hands-on learning, which are skills that are transferable to other subjects and real-life situations. Additionally, the collaboration between schools, industry partners, and research institutions has fostered a vibrant ecosystem of innovation and learning in Wuxi. Students now have access to new technology and resources, and they have opportunities to engage in real-world projects and research that can have a tangible impact on society. This collaboration has also opened up new avenues for career exploration and networking for students, preparing them better for the challenges and opportunities of the future workplace.

In conclusion, the implementation of engineering education strategies in Wuxi has not only deepened students' understanding and interest in engineering but has also had a transformative impact on the education system as a whole. It has equipped students with valuable skills, fostered innovation, and laid the groundwork for the development of a thriving engineering community in the city.

3.2. A Strategic Approach to Shaping Engineering Attitudes Among Elementary and Middle School Students

In alignment with the implementation pathway of engineering education in primary and secondary schools within Wuxi City, and grounded in the ABC (Affect, Behavior, and Cognition) theory of attitudes, the cultivation of engineering attitudes can be initiated from three dimensions: cognitive, affective, and behavioral intention. The construction of strategies across these dimensions is guided by the following principles: clarifying objectives, designing practical activities, fostering positive beliefs, and reinforcing positive behaviors. Each dimension is based on activities, but the focus is different in the activities. The cognitive dimension focuses on the construction of basic cognitive knowledge in engineering education, the affective dimension focuses on cultivating an interest in engineering, and the behavioural intention dimension focuses on stimulating a sense of participation, practical ability and career awareness in engineering.

3.2.1 Cognitive Dimensional Strategy
3.2.1.1. Curriculum Optimization

Taking into account the cognitive characteristics and interests of elementary and middle school students, an engaging and informative engineering education curriculum should be meticulously crafted. The curriculum content should encompasses engineering narratives, basic engineering design cases, and other relevant topics, fostering an environment where students can acquire engineering knowledge in a relaxed and enjoyable manner. For instance, by narrating stories of engineers, students gain insight into the fascination and significance of the engineering profession. Meanwhile, through the presentation of simple engineering design cases, students understand the processes and methodologies involved in engineering design. In lower grades, the curriculum emphasizes engineering stories and fundamental phenomena to spark curiosity; whereas in higher grades, it progressively introduces engineering design and practical content to enhance students' cognitive and practical abilities. For instance, lower grades may offer a "Mysteries of Engineering" course to introduce students to the basic concepts and application areas of engineering, while higher grades may provide a "Engineering Design and Production" course to allow students to experience the process of engineering design and production. Furthermore, engineering knowledge is integrated with other disciplines, such as mathematics, physics, and science, to nurture students' comprehensive thinking abilities.

3.2.1.2 Enrichment of Science Popularization Activities

Firstly, vibrant and diverse science activities, such as science and technology lectures, science exhibitions, and hands-on science experiments, are actively organized. Professional engineers or scientists are invited to elucidate engineering knowledge to students, thereby stimulating their interest in learning. For instance, engineers can explain the working principles and application areas of robots to students, and organized visits to science exhibitions can expose students to the latest achievements and technologies in the engineering field. Secondly, a science exhibition area is established within the school premises to showcase the latest advancements and technologies in engineering, enabling students to access engineering knowledge at any time. Specifically, a robot display area and a 3D printing exhibition area can be set up on campus, allowing students to explore the latest innovations in the engineering field after school hours. Thirdly, the Internet, multimedia, and other information technologies are leveraged to conduct online science popularization activities, broadening the reach and impact of these initiatives. For example, students can engage with engineering learning at home through the production of science videos and participation in online science lectures.

3.2.1.3 With the Help of Information Technology

Firstly, virtual reality, augmented reality, and other information technologies are fully leveraged to provide students with intuitive and engaging engineering learning experiences. For instance, the virtual laboratory enables students to conduct engineering simulation experiments, thereby enhancing their knowledge and comprehension of engineering principles. Specifically, students can undertake circuit experiments, mechanical design experiments, and more through the virtual laboratory, immersing themselves in the processes and methodologies of engineering experiments within a virtual environment. Secondly, the campus network platform is harnessed to disseminate engineering education resources, facilitating students' autonomous learning. Furthermore, an online learning community is established to facilitate the exchange of learning tips and experiences among students, ultimately improving their learning outcomes.

3.2.2. Emotional Dimension Strategy
3.2.1.1. Organization of Practical Activities

By addressing real-world problems, students are granted ample opportunities to practice, explore, and apply disciplinary core concepts, mirroring the approach of scientists and engineers. This fosters connections between disciplinary content across various domains through crosscutting concepts .[vi] Various practical engineering activities, such as robotics competitions, science and technology innovation competitions, and handicrafts, are organized to let students experience the joy and sense of accomplishment inherent in engineering practice, thereby igniting their interest and passion for engineering. Practical activities emphasize student participation and sensory experiences. Additionally, in conjunction with campus cultural activities, engineering-themed cultural performances, painting competitions, and other events are conducted to bolster students' emotional identification with engineering. For example, engineering-themed art performances can be organized during the campus culture and art festival, while the campus painting competition can serve as a platform for students to express their admiration and aspiration for engineering.

3.2.1.2. Organization of Competitions

A diverse array of engineering competitions is organized to provide students with a vast stage to showcase their talents. An extensive range of awards and honors is established to stimulate students' sense of competition and honor, allowing them to demonstrate their skills and practical abilities in the competitions. Meanwhile, the competition results are publicized across the campus to foster a robust engineering atmosphere. For instance, the list of competition winners and works can be displayed prominently on campus, immersing students in the vibrant and captivating ambiance of engineering competitions. Furthermore, the competition results can be disseminated through campus radio, school newspapers, and other media, ensuring that more students are apprised of the situation and significance of the engineering competitions.

3.2.1.3. Strengthening Emotional Education

Teachers emphasize emotional education in the teaching process, stimulating students' affection and respect for engineering by sharing inspirational stories and showcasing engineering achievements. For example, teachers can narrate the struggles and triumphs of renowned engineers, such as Edison's invention of the electric light, to instill in students the perseverance and innovative spirit of engineers. Additionally, teachers can present significant engineering achievements, like the construction of the Hong Kong-Zhuhai-Macao Bridge, to make students appreciate the grandeur and magic of engineering. Furthermore, in conjunction with campus culture, engineering-themed class meetings, team activities, and other events are conducted to enhance students' teamwork spirit and sense of collective honor. For instance, a class meeting themed "Engineering and the Future" can be held for students to deliberate on the impact of engineering on society's future, fostering their sense of responsibility and mission towards engineering. Engineering team activities, such as collaborative model-making, can be organized to cultivate students' teamwork and communication skills. Attention is paid to students' emotional needs, with timely encouragement and support provided to bolster their self-confidence and learning motivation.

3.2.3.Behavioral Intention Dimension Strategy
3.2.3.1 Conducting Community Activities

Engage students in engineering club activities, including robot programming clubs and 3D printing clubs. These clubs offer platforms for students to enhance their engineering practical skills and innovative capabilities. The clubs are independently organized and managed by students, with teachers providing guidance and support. This approach fosters students' independent learning abilities and teamwork spirits. For instance, students can autonomously plan club activities, orchestrate their implementation, and manage club affairs, while teachers offer technical guidance, safety supervision, and security measures.

3.2.3.2. Encouraging Volunteerism

Promote student participation in volunteer service activities, such as educating community residents on basic engineering knowledge and engaging in environmental protection projects. These endeavors cultivate students' senses of social responsibility and dedication. Additionally, they can take part in environmental engineering activities, such as garbage classification campaigns and tree planting initiatives, to contribute to environmental protection. Volunteer activities should emphasize the integration of engineering education, enabling students to apply their acquired engineering knowledge and skills in volunteer service to enhance their practical application abilities.

3.2.3.3 Providing Vocational Guidance

Offer career guidance to students to help them comprehend the prospects and requirements of engineering careers. Invite engineers or enterprise representatives to deliver career talks to students and organize visits to enterprises to enable students to understand the actual working environments and demands of engineering careers. Conduct activities themed around career planning, such as career planning competitions and career experience simulations, to assist students in establishing correct career perspectives, formulating career plans, and improving their career planning abilities through presentations and exchanges. Career experience activities can be organized to simulate engineering career work scenarios, allowing students to experience the work content and requirements of engineering careers. Focus on students' career interests and strengths, providing them with personalized career guidance and advice.

In today's era of rapid technological advancements, engineering plays a pivotal role in social progress and economic development. Cultivating positive engineering attitudes among primary and secondary school students can pave the way for nurturing future engineering talents and fostering the country's scientific and technological innovation and economic growth. However, this study has some limitations, and future research can delve deeper into the following aspects: strengthening research on the equalization of educational resources, continuously innovating teaching methods, conducting in-depth studies on individual student differences, increasing society's emphasis on engineering education, and reinforcing the role of family education in engineering education. In conclusion, shaping engineering attitudes among primary and secondary school students is a long-term and intricate systematic project that necessitates the concerted efforts of schools, families, society, and the government. Future research should continue to explore and innovate to provide more scientific and effective strategies and methods for shaping the engineering attitudes of primary and secondary school students, thereby contributing significantly to the cultivation of engineering talents with innovative spirits and practical abilities.

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Assessing Pupils' Creative Design Ideas and Prototypes Using Comparative Judgment

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Abstract

Developing creative designs and leveraging technology to shape and improve our surroundings are important 21st-century competencies, receiving growing attention in K-12 education. This paper presents a work-in-progress that (1) details the selection and development of a design task, 'SnackSafe on the Beach,' which challenges pupils to creatively ideate and sketch their design prototypes within 40 minutes, and (2) explores the criteria for design creativity applied by expert judges when using comparative judgment (CJ) to assess pupils' design ideas and prototypes. 24 pupils (M_age = 12.59 years) from an international school in the Netherlands generated creative ideas and developed design prototypes for the design task. Six industrial designers were trained to use CJ to evaluate the creativity of pupils' designs. Our preliminary analysis reported CJ-generated scores of creativity seen in design ideation and prototypes. Additionally, qualitative findings from judges' interpretations of creativity in pupils' design works provided practical insights into assessing creativity in the context of design and technology education.

Key Words: Children's Design, Comparative Judgment, Creativity, Design Ideation

1. INTRODUCTION

Various factors can affect the learning of Design and Technology (D&T), such as learners' attitudes (Vossen et al., 2018), problem-solving skills (Schooner et al., 2017), and peer collaboration (Hennessy & Murphy, 1999). Among these, creativity—one of the key 21st-century competencies (Voogt & Roblin, 2012)—is widely recognized as a crucial factor driving innovative designs (Lewis, 2005; Sarkar & Chakrabarti, 2011). The National Curriculum for Design and Technology subject in England, for instance, highlighted one of its learning goals as for pupils to "develop the creative, technical and practical expertise needed to perform everyday tasks confidently and to participate successfully in an increasingly technological world" (Department for Education, 2013).

D&T classrooms appear to be an ideal setting for exploring how pupils use and develop creativity. Much research has shown that design projects foster the need for and expression of creativity among pupils (Cropley & Cropley, 2010; Benson & Lunt, 2011). However, adequately evaluating how pupils have been using their creativity in a D&T project remains a challenge to this day, both in selecting the appropriate task for assessment and in determining how to evaluate the intermediate and final outputs generated from these tasks.

To assess creativity as a cognitive or psychological construct, psychologists have developed test-based measures that are context-independent, making them generalizable across large samples with established scoring guidelines that can be applied by trained raters. However, these creativity measures may not fully capture the nature of creativity within the Design and Technology learning environment, where projects are not only open-ended but also context-specific and rooted in authentic real-world problems (Kimbell & Stables, 2007). Therefore, a design task that is based on real-world problems, adaptable to various contexts, can be solved from different directions or perspectives, and can be used to assess certain qualities of pupils, such as creativity, empathy for users, or problem-solving abilities, could be beneficial for D&T researchers and educators.

1.1. Assessing qualities of works in D&T projects and the use of comparative judgment

Evaluating responses to open-ended tasks, such as those focused on creativity or divergent thinking, has been a challenging topic for both educators and researchers. Traditional methods that rely on predefined scoring rubrics can often be time-consuming and costly, accompanied by complications that arise from disagreements among judges (Forthmann et al., 2023) and judge fatigue (Forthmann et al., 2017). Objective techniques, such as those suggested by Shah and colleagues (2003), have been frequently applied to assess engineering design products. However, Sluis-Thiescheffer et al., (2016) found it difficult for judges to be consistent when using this approach to assess the creative value of children's design works.

In contrast to assessing the quality of works against set criteria, comparative judgment (CJ) reveals the relative quality of pupils' works by having expert judges compare pairs of works in a series of rounds. Studies employing adaptive comparative judgment to evaluate the qualities of works from design and technology education in secondary or higher education contexts have reported high reliability coefficients, ranging from 0.93 to 0.97 (Bartholomew et al., 2018a; Bartholomew et al., 2018b; Buckley et al., 2022; Seery et al., 2019). Besides generating rankings useful for summative assessment (Newhouse, 2014), comparative judgment also appears to be a useful formative assessment tool that can contribute to students' understanding of quality D&T works (Bartholomew et al., 2018b; Seery et al., 2019).

A majority of the studies in D&T education that have utilized comparative judgment focused on holistically assessing the quality of produced design works (Kimbell, 2011; Seery et al., 2019; Strimel et al., 2021), or in other words, choosing the piece of work that is overall better than the other one in the pair. Since many factors can influence the perceived quality of design works, having judges use their professional knowledge to assess the overall qualities of works inherently suggests that they may apply varying criteria during evaluation. Qualitative findings from Buckley and colleagues (2022) revealed the diverse criteria judges used to select a winning design portfolio from a pair. These included the quality of crafting seen in the work, the quality of the design concept, effectiveness in communication and presentation, emotion conveyed through the design, and the amount of effort or details evident in the design. Interestingly, how creative, unique, interesting, or adventurous the designs were seemed to be less frequently mentioned as a criterion. Similarly, in the qualitative data reported by Bartholomew and colleagues (2018a), it appeared that more emphasis was placed on the suitability and feasibility of the design, the aesthetics, the completeness of the portfolio, reflection seen in the process, with creativity and innovation comprising as little as 5% of the comments made by judges. These findings are somewhat surprising, given that creativity has been widely deemed as a critical, even central, element of design quality. To gain a better understanding of creativity seen in young pupils' design work, we aim to use comparative judgment to assess design quality with a specific focus on having judges choose the more creative piece of work, rather than the overall better one, from pairs.

Our investigation is part of a larger research project examining the link between creativity in design and spatial ability. In this work-in-progress, we aim to (1) explore the feasibility of using a brief design task, which can be approached from multiple directions, to assess pupils' abilities to generate creative design ideas and prototypes, and (2) examine the criteria expert judges apply when using comparative judgment to evaluate pupils' design ideation and prototypes, with a particular focus on the criteria for creative designs.

2. METHODOLOGY

2.1. Participants and setting

24 pupils (13 boys, 11 girls, M_{age} = 12.59 years, SD = 0.61) from an international school in the Netherlands participated in this study during their regular design lesson time in their design classroom. Informed consent to participation was obtained from both the pupils and their parents or guardians.

Six current or recently graduated master's students from the Department of Industrial Design Engineering at Delft University of Technology were recruited as judges. Five of these judges had experience in courses or projects related to designing for or co-designing with children. This background provided them with some understanding of children's design and sketching.

2.2 Selecting and adapting the design task

The SnackSafe on the Beach design task used in this study was inspired by a design problem related to the annoyances caused by seagulls, developed at the Science Hub at TU Delft[1]. This authentic and engaging design challenge was originally instructed in Dutch and has been carried out in multiple Dutch primary and secondary schools. Most pupils were unfamiliar with known solutions to this challenge, prompting them to seek solutions from different angles. This open-ended approach is desirable as it encourages diverse interpretations and problem-solving strategies, fostering 'thinking in different directions' (Klapwijk et al., 2021).

For research purposes, we made several adaptations to the design prompt and procedure. First, we focused the design challenge on solving the problem of helping people eat fries on the beach without being bothered by seagulls (Figure 1). Second, we identified key steps in problem exploration, idea generation, and concept development that could be done individually. These steps were incorporated into an A3-size foldable design booklet to capture pupils' thought processes when solving the design challenge. To assess individual pupils' performance, they were asked to complete all the steps individually, without collaboration. The booklet's design was inspired by the design portfolio developed in the TERU project (Kimbell & Stables, 2007; Stables & Kimbell, 2000), which aimed to document pupils' idea progression, intermediate products, and reflections to illustrate the dynamic design process.

Figure 1.
The 'SnackSafe on the Beach' Design Task

[1] https://www.ontwerpenindeklas.nl/les/overlastmeeuwen/

2.3. Organizing the design challenge and the comparative judging sessions

2.3.1. The energizer and the design task

All design sessions began with a five-minute energizer to stimulate pupils' thinking and engagement. This practice, recommended by experienced design educators, helps to make participants feel comfortable expressing ideas and thinking actively in different directions (Klapwijk et al., 2021). The pupils were asked to list as many fruit names as they could think of within one minute and then stand up when the time was up. Those who had either 'apple', 'banana', or 'strawberry' among their first three names were then asked to sit down. Following this activity, the pupils were informed: "Oftentimes when we are asked to come up with many ideas, our first few ideas are usually not very uncommon or unique. However, by continuing to generate more ideas, you may come up with more unusual, uncommon, and even creative ideas, or you might be able to make links between ideas to create unique combinations."

Next, the pupils were guided through the design booklet. The researcher read the design problem aloud and instructed them to spend three minutes writing down keywords for the features they thought their design needed to have in order to solve the design challenge. They were then asked to brainstorm as many ideas as possible on an A4 sheet with six empty boxes. Pupils were encouraged with the prompt: "All ideas are welcome. Don't hesitate to sketch anything that comes to your mind. Every new idea can be a valuable addition." Our prompt drew inspiration from known brainstorming rules advised by experienced designers, design educators, and researchers (IDEO.org, 2015; Klapwijk et al., 2019).

Following this, pupils were explicitly instructed to be creative and generate four additional ideas, which could either be entirely new or improvements on previous ideas. They were further advised: "Try to think of unusual, original, exciting ideas that others won't easily think of. Think from different viewpoints and explore different directions. You can also jot down improved versions of your previous ideas or make unique combinations between your ideas." This instruction, adapted from Butler (1987) and drawn from the YourTurn Design Tool created through a collaboration between Delft University of Technology and Goldsmiths, University of London (Klapwijk et al., 2019; Klapwijk et al., 2021), aimed to clarify the goal of the task, sustain pupils' engagement, encourage divergent thinking, and emphasize the importance of exploring different directions while postponing judgment.

After generating as many ideas as possible, pupils were instructed to individually select and circle the idea they considered the most unusual and original for solving the design challenge. They then developed detailed sketches of their chosen ideas, adding annotations to help others understand their design prototypes. Each pupil was given 40 minutes to complete both ideation and prototype sketching, using only pencils for all sketches and notes. They received equivalent instructions, materials, and resources. The above-mentioned prompts were intended to facilitate their idea development process and mimic typical classroom design project practices.

2.3.2. The comparative judging process

All ideas and design prototypes were photographed, anonymized, and uploaded to an online comparative judgment platform, No More Marking, to create two CJ sessions. Figures 2 and 3 show the interfaces presented to the judges, where pairwise comparisons of pupils' ideas or design prototypes were generated by the systems' algorithm.

Figure 2.
CJ session for pupils' ideation: judges were asked to compare the creativity of the entire set of ideas from the pupil on the left with that of the pupil on the right

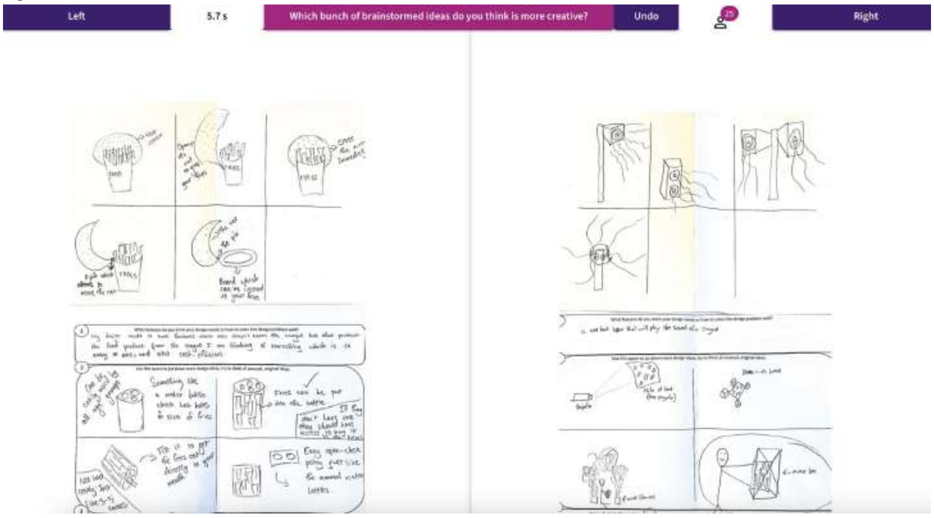
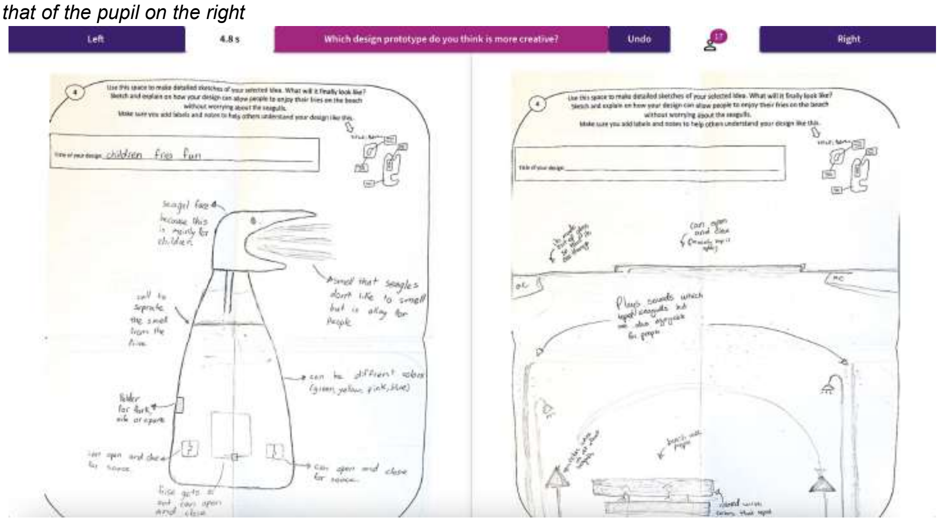


Figure 3.
CJ session for pupils' sketched prototypes: judges were asked to compare the creativity of the sketched design prototype from the pupil on the left with that of the pupil on the right



Each judge was introduced to the design assignment and trained to use the comparative judgment platform. Judges were told to use their industrial design knowledge as criteria for assessing creative designs. The prompts displayed above each pair of works—either 'Which bunch of brainstormed ideas do you think is more creative?' or 'Which design prototype do you think is more creative?'—were made to keep the focus of the assessment on creativity. Each judge practiced making five comparisons of pupils' brainstormed ideas and design prototypes separately to ensure they understood the comparative judgment process and had a basic understanding of the pupils' design levels. Judges were also encouraged to add comments to pupils' work when possible to help us better understand the criteria they used to evaluate why one piece of work was deemed more creative than another.

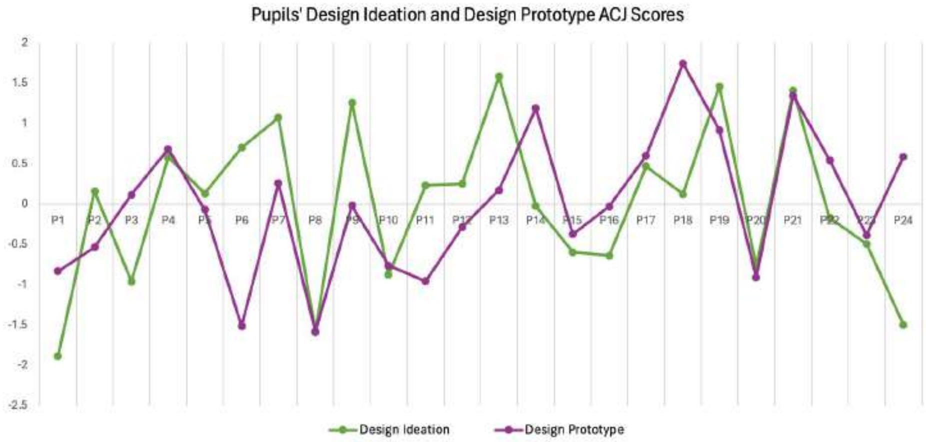
Each judge completed 40 pairwise comparisons ([24 pieces of work × 10]/6 judges) separately for pupils' ideation and design prototypes. The comparative judgment sessions were completed individually, with each judge working at their own pace. All judges first completed the judging session on design prototypes, followed by the session on design ideation (brainstormed ideas). This sequence was intentional, as seeing the annotated design prototypes first would help judges better comprehend the brainstormed ideas, which were often simple sketches without annotations.

3. FINDINGS AND DISCUSSION

On average, the median time spent by the judges was 121.7 seconds for judging design ideation and 120.3 seconds for judging design prototypes. Using the Supplementary Item Response Theory Models ('sirt-package') in R studio, we calculated the scale separation reliability (SSR) for the design ideation judging session (.772) and the design prototype judging session (.731), indicating acceptable internal consistency.

The correlation between the true scores pupils received for design ideation and design prototype was moderately strong, $r(22) = .408$, $p < .05$. Pupils' scores were mapped onto a line graph (Figure 4) to show how their scores for ideation and prototypes compared.

Figure 4.
Pupils' true scores for design ideation (brainstormed ideas) and design prototypes, calculated based on judges' decisions



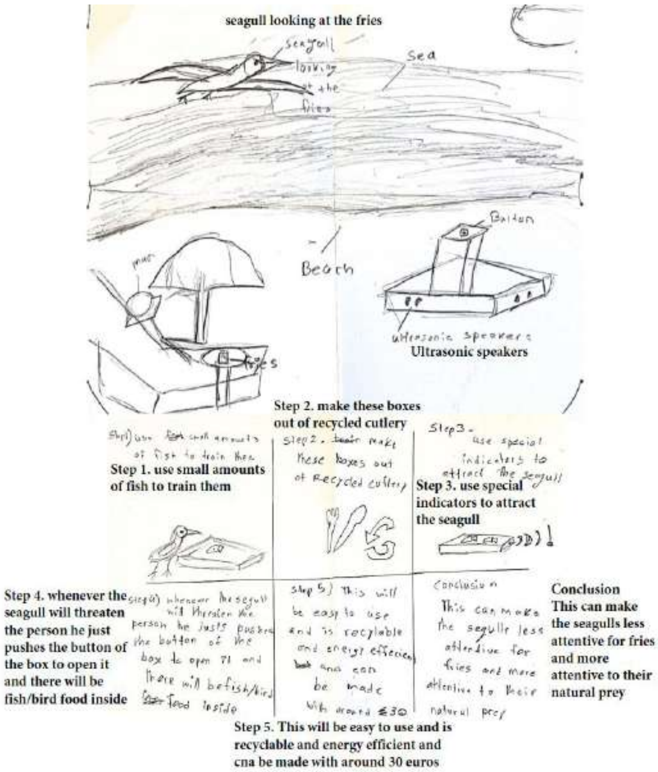
The six judges made a total of 169 comments regarding the pairwise comparisons of pupils' brainstormed ideas and 183 comments regarding their design prototypes, revealing the criteria they applied to assess creativity in pupils' design works. Through bottom-up coding, we identified key themes related to creativity (Table 1).

Table 1.
Themes identified from judges' comments about why one piece of work is more creative than another in pairwise comparisons

Session/Theme	*Themes appeared in all six judges' comments*	*Themes appeared in more than half of the judges' comments*
Assessing design ideation	*Having more different and varied ideas*	*Having more feasible and less unrealistic ideas*
	Exploring more different design directions before concluding (broad & open to further development vs. narrowed & focused)	*Having more elaborated and detailed ideas or more thought-through concepts*
Assessing design prototypes	*Having more out-of-the-box and less obvious solution*	*Solution having multiple features or uses*
	Having detailed and well-thought-through solution	*Solution tailored to the beach context*
	Having more feasible or practical solution	

Below (Figure 5) is the design prototype that received the highest score for creativity in this sample. It reflects several comments frequently mentioned by judges: it is rather original while still being feasible, detailed, well-thought-through, considered various aspects, and fitted for the beach context.

Figure 5.
Highest-scored design prototype (the pupil's written description has been typed out for clarity)



4. CONCLUSION

The results from our preliminary analysis added to our understanding of developing brief design tasks to assess pupils' ability to make creative designs, as well as using comparative judgment to evaluate specific qualities, such as creativity, in design works. Our findings can be summarized in two main points.

First, it is important to note that our design task, 'SnackSafe on the Beach,' was not intended to assess pupils' overall design capability, as it did not include several key steps in the design process, such as user research, iterating, or testing. Instead, this brief yet engaging task was developed to provide insight into how pupils spontaneously apply their creativity to solve a design problem. While this design task may resemble some known creativity or divergent thinking tests—such as prompts asking pupils to think of as many different and unusual uses for a brick—it differs by offering pupils a real-world context and challenging constraints similar to those found in typical classroom design projects. Therefore, this design task could potentially serve as a practical, in-between tool for those interested in assessing pupils' creativity with a real-world-originated design problem that can be built upon, especially for those with limited time and resources to carry out an entire design project.

Second, in comparative judgment, when judges were asked to choose the more 'creative' design rather than the 'better' one, their comments indicated a focus on the creative or innovative aspects of pupils' design and sometimes noted creative behaviours exhibited during the ideation process, such as exploring different directions or reframing the problem in unexpected ways. However, judges also frequently mentioned usability and details as key criteria for their decisions, aligning with the categories of criteria reported by Bartholomew et al., (2018a) and Buckley et al., (2022). This emphasis on usability is not surprising, as there is a consensus that creativity in Design and Technology requires the product to be not only novel but also functional and effective (Cropley & Cropley, 2010).

5. ACKNOWLEDGEMENTS

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Abstract

Practical Cases of Pre-Service Training for K-12 Technology Teachers Based on Innovative Design of Chinese Chess

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Abstract

The technology practice curriculum occupies an important position in the pre-service education system for K-12 technology teachers. The pre-service teacher training course introduced in this study adopts a project-based teaching approach, with the theme of "Innovative Design of Chinese Chess." Under this framework, students utilize their professional knowledge and skills to develop a series of innovative and practical chess sets centered around the traditional theme of Chinese chess, incorporating modern technological elements through diversified technical means. To systematically organize and document these design and production achievements, students collectively compiled a technology portfolio, which details the design ideas, implementation processes, product introductions, and reflections on the learning outcomes throughout the production. This study will present and discuss the works of pre-service teachers based on this technology portfolio. By sharing these achievements, the aim is to explore the enhancement effects of this project on five competency dimensions of pre-service K-12 technology teachers: technological awareness, engineering thinking, innovative design, graphical expression, and materialization ability. Consequently, this study provides insights and references for the pre-service training of K-12 technology teachers.

Key Words : K-12 Technology Teachers, Pre-service Training, Technology Practice Curriculum, Innovative Design of Chinese Chess

The educational function of public welfare K-12 STEM education and its realization

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Abstract

Educational equity means that regardless of individual family background, region, and economic status, everyone should have equal opportunities to access high-quality educational resources, and get equal support and development opportunities in the education process. STEM education is often considered to require certain experimental equipment and site support, which undoubtedly poses challenges for rural and economically backward areas. It is therefore critical to ensure that every student - regardless of gender, race, origin or region - has access to quality science and technology education resources. The purpose of this study is to introduce a series of public welfare STEM education activities that our science caravan team of Nanjing Normal University has been continuously carrying out in the past ten years, which aims to publicize and disseminate scientific methods, scientific spirit and scientific ideas, popularize applied technology, introduce scientific frontiers, and deliver science and technology education resources to teenagers and children in various regions of China in various modes. This includes, but is not limited to, regular shuttle buses based on open laboratories, demonstration science popularization in communities, special sessions at provincial book fairs, cooperation projects with science and technology venues, and scientific assistance for poor areas. In this process, we encourage participants to "learn by doing" and develop a series of low-cost projects focusing on scientific inquiry and technological creation. We believe that even simple objects in life can be designed to be interesting to children. Through simple explanation and demonstration, it lays a foundation for cultivating children to become creative talents, stimulating their scientific interest, improving their scientific literacy, and exercising their practical skills.

Key Words: Public welfare K-12 STEM education, educating function, realization path

A study on learning strategies for the cultivation of children's engineering thinking

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Abstract

This study points to the cultivation of children's engineering thinking, focusing on how to develop children's higher-order thinking and core literacy through classroom learning support strategies. Engineering thinking is a highly integrated planning, design, construction, and practical thinking, which can integrate and apply multiple knowledge to solve practical problems. With the deepening of China's education reform, engineering thinking has gradually become an important part of core literacy and has been included in the primary school science curriculum standards. The engineering thinking goal of engineers is manufacturing, while the training of children's engineering thinking is more exploratory and developmental, focusing on the ability to solve complex tasks through the learning of engineering themes that "start with the end in mind" in primary school science classrooms.

This study views children's engineering thinking as a type of higher-order thinking capable of integrated problem solving, based on engineering challenges, which children gradually develop in line with their cognitive level by applying knowledge and skills from multiple disciplines to solve specific engineering tasks. In this study, we introduced classroom learning support strategies such as "planning for difficulties and weigh options to promote thoughtful decision-making." to help children become active problem-solving masters in the learning of engineering topics. Specific classroom strategies include brainstorming, affinity diagrams, evidence-based decision-making, round-robin strategies, and open-circle refining 1:4 strategies to optimize group cooperation and improve children's learning effectiveness. Through these support strategies, the aim is to explore how to cultivate children's engineering thinking and develop their systematic and comprehensive problem-solving skills in primary science education, so as to improve children's core literacy and lay a solid foundation for children's future innovative practice ability.

Technology & Engineering Education in Cambodia: The Case of Primary and Secondary School

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Details Include:

- Cambodia Education Systems
- Digital tools to support K12 students
- Digital tools to support K12 teachers
- Digital platform to support K12 besides study hour
- Role of the Department in promoting Technology and Engineering

Positioning and Solving Difficulties, Effective Exploration of Regional Promotion of Technology and Engineering Education

Jianhua Lang, Wenzhou Institute of Education and Teaching

Summary

This article reviews the process of promoting technology and engineering education in the region over the past decade, focusing on the difficulties, difficulties, and doubts in the process of regional promotion; Research effective strategies and methods for solving difficulties, overcoming difficulties, and resolving doubts, identify regional positioning, break through the cohesion from multiple aspects such as curriculum, teachers, space, projects, evaluation, and teaching research, deeply tap into the regional ability to promote technology and engineering education, solve various problems in promoting engineering, and achieve effective development of technology and engineering education in the region.

Key Words: Technology and Engineering Education Positioning and Difficulty Solving Projects

Main outline

(i) The Curriculum and Value of Technology and Engineering Education
(ii) Difficulties, Difficulties, Puzzles, and Countermeasures in Promoting Regional Technology and Engineering
(iii) Identify the suitability positioning of regional technology and engineering education,
(iv) Breaking through the cohesion of curriculum, teachers, space, projects, evaluation, teaching and research, and achieving effective development of technology and engineering education in the region

The Design of a Learning Project Integrating Physics and Technology & Engineering Education in a Project-Based Learning Model

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Abstract

Students' scientific thinking, as well as their technological and engineering thinking, are typically cultivated within the framework of subject-specific curricula. This study innovatively integrates the content of mainland China's high school physics curriculum with that of the general technology curriculum, utilizing project-based learning as the foundational framework to design a hands-on student learning project. The project, themed "The Design and Application of an Accelerometer," combines the core knowledge of Newton's Second Law from physics and the core principles of the technical design process from general technology. Through project-based learning, students are guided to engage in interdisciplinary collaborative inquiry and creation in the context of real-world engineering problems.Teachers guide students to work in groups to conceptualize and design four different types of accelerometers, helping students gain practical experience at the intersection of physics knowledge and technical skills. Each group first designs an accelerometer based on physical principles, enhancing their technical awareness and diagrammatic representation skills. In the hands-on production phase, groups exchange design plans, further refining their engineering thinking and materialization abilities. During the technical experimentation stage, students use the accelerometers they have built to perform acceleration measurements, applying theoretical knowledge to real-world scenarios, testing the accuracy and precision of their designs, and deepening their understanding of both physics and technology.By integrating physics and technology, the project not only enhances students' academic proficiency in physics but also strengthens their innovative design abilities. Through this interdisciplinary project, students gradually develop a positive attitude toward science and technology and experience the practical applications of technology in everyday life. This teaching model helps cultivate students' comprehensive scientific literacy and engineering practice skills, offering new insights for K-12 technology and engineering education as well as student development.

Key Words: Project-Based Learning, Interdisciplinary Education, Physics and Technology Integration

The application of project-based learning in general technology courses from the perspective of knowledge integration

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Abstract

In the process of engineering transformation of technical education, the cultivation of engineering thinking has become the focus of attention. As one of the five core competencies of China's general technology curriculum, the development of students' engineering thinking can provide a solid foundation for the improvement of other core literacies. However, the current research on the cultivation of students' engineering thinking mainly focuses on the engineering itself, and pays too much attention to the quantity, difficulty and novelty of engineering in teaching, while there is a relative lack of research on the teaching mode of cultivating engineering thinking. Project-based learning from the perspective of knowledge integration combines theoretical learning with practical learning, presents systematic and diversified learning materials by creating integrated real problem situations that can support the entire project learning process, and organizes purposeful and directional cooperative inquiry and other teaching activities, so as to finally solve real problems and form project products. In this process, students will enhance their knowledge and understanding of general technologies, develop engineering thinking, and learn to interpret, understand and feel the world from the perspective of technology, so as to have core literacy such as future-oriented migration and application.

Key Words: Engineering thinking, Project-based learning, Knowledge integration

High School Students as Co-Producers of Technologies for Sustainable Development

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Abstract

This research presents two case studies that demonstrate the active role of students as co-producers of robot and educational website promoting sustainable development. In Case 1, my Grade 10 students in Research Class created an assistive wearable robot that responded to the needs of the visually impaired people (VIP) who worked as massage therapists in Cebu City, Philippines. Together with the Robotics Teacher, we used the Robotee Solution Framework in designing the assistive cap: Envisioning, Planning, Developing, Stabilizing, and Deploying. Results showed that the VIPs approved the cap's physical qualities: comfort, material used, weight and usability, and system design. The percent of error calculations and some test sases for the SMAK's functionality show that the cap is accurate (≈ 99.79% of accuracy) in detecting obstacles in less than 1.5 meters. My Grade 10 students felt satisfaction and fulfillment in applying their Robotics and research skills to the VIP. In Case 2, another group developed an educational website promoting the local history of Cebu. From the Needs Assessment, they found out that many students lacked local history knowledge. Their website featured Cebu before and after the Spanish colonization. It underwent Expert's Evaluation and pilot testing which received positive evaluation. The website was used by Grade 8 students in learning history. Findings from the Grade 8 students' pretest-posttest scores showed a significant mean gain in understanding Cebu local history. In the FGD, the Grade 10 students claimed that the project developed their self-esteem and more knowledge about local history.

From Physics to Technology Education

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Abstract

Technology and engineering education in China goes beyond classroom instruction, often manifesting through the integration of technology and engineering into science education. Physics, a core subject in China's middle and high school entrance examinations, is also one of the subjects most closely related to secondary school science education. At this level, physics and technology-enhanced science education mutually reinforce each other. By applying physics principles, students can easily create scientific projects such as water rockets, catapults, and load-bearing bridges. These projects are based on concepts from mechanics and electromagnetism, and the process of designing and constructing them helps students develop technical skills and engineering thinking. Technical skills and projects also enhance students' understanding of physics. Sensor technology has already been introduced into some high school physics classrooms, where many students use DIS (Data Integrated Systems) technology to assemble components, improving and optimizing textbook physics experiments. Information technology has also been employed to create various physics experiment tools, such as Phyphox and the author's own Optical Wave Demonstration System, providing interactive, self-directed learning experiences that have yielded positive results. Through interdisciplinary approaches that leverage physics and science education, the integration of technology and engineering into secondary science education serves as a means of introducing students to technical education and skill training. This not only improves students' technical and engineering competencies but also fosters curiosity, imagination, creativity, and a sense of value in science and technology. The pathway from physics to technology could potentially be a breakthrough in advancing technical and engineering education in Chinese secondary schools.

Key Words: Technology Education, Science Education, Physics Education, Interdisciplinary Approaches

Analysis on the Design Ideas and Characteristics of Physics Course Materials of Five-year Consistent Higher Vocational and Technical Education from the Perspective of Cultivating High-level Technical Talents

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Abstract

Currently, vocational and technical education is an important educational model in China that distinguishes it from general high school education. A portion of Chinese students will be streamed into vocational and technical schools after the middle school examination to specialize in technical studies. Physics is an important basic compulsory course for vocational-technical school students in some specialties (e.g., machinery-construction, electronics-information, etc.). Jiangsu Province has explored a special vocational education model for a five-year high school program. In this study, structural analysis and psychoanalysis were comprehensively used to analyze in detail the five-year higher vocational physics standard textbook in Jiangsu Province, which was developed and completed in 2024, and to explore in depth whether the textbook highlights the characteristics of the type of vocational and technical education and the cultivation of the necessary qualities for future high-level skilled personnel. The analysis shows that the textbook reflects the importance of technical education from the chapter introductory page and section introductions to the context of the topics chosen in the main text, as well as the featured section "Life-Physics-Society". The analysis confirms that the textbook not only integrates the core qualities and contents of the physics discipline in a comprehensive way, but also follows the progressive law of the growth of technical and skilled talents, highlights the characteristics of the cultivation of technical and skilled talents in a long period of time, and is able to effectively improve the quality and influence of vocational and technical education and the quality of the cultivation of talents in the five-year senior vocational education system.

Key Words : Physics curriculum for vocational and technical education, analysis of teaching materials, integration of physics and technical education, training of high-level skilled personnel

Cultivation mode of technical talents in new energy vehicle application and maintenance in secondary vocational education：A comparative analysis of talent cultivation programs of six secondary vocational schools

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Abstract

This paper compares and analyzes the cultivation objectives, cultivation specifications, curriculum construction, and implementation guarantee in 6 cultivation programs of new energy vehicle application and maintenance. Through the text analysis, it is found that the cultivation objective is based on literacy, but the level is unclear. The cultivation specification corresponds to the objective, which is divided into three dimensions of knowledge, ability and literacy, highlighting the characteristics of the profession. Each school has developed a curriculum system, forming a relatively complete curriculum structure, with schools in the eastern region performing even better. However, a common issue among all the six schools is the excessive teaching load. In terms of implementation guarantee, schools in eastern region have abundant resources to support professional development, and the school-enterprise cooperation of schools in the central and western regions is not targeted enough.

Key Words : technical talent cultivation, cultivation programs,secondary vocational school

Cultivating Technical And Engineering Thinking In Primary Education

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Abstract

At the 2021 Academician Conference of the Chinese Academy of Sciences and the 10th National Congress of the China Association for Science and Technology, President Xi Jinping underscored that the crux of international competition revolves around talent and education. To attain self-reliance and strength in science and technology, it is essential to establish a robust talent cultivation system and create an environment favorable for the growth of scientific and technological talents. Primary and secondary technical and engineering education assumes a vital role in this process, fostering students' technical and engineering mindsets through multifaceted activities. The instruction of engineering thinking, given its latent, developmental, and individualized nature, presents pedagogical challenges; however, visualizing thought processes through problem-solving has been verified as an efficacious method, albeit with the design of such problems posing a significant challenge. Presently, diverse educational theories align with engineering education, including Project-based Learning, Problem-based Learning, and Deep Learning. This research endeavors to consolidate these methodologies, thereby summarizing a novel teaching model aimed at enhancing the cultivation of engineering thinking.

In conclusion, this study employed a combination of literature review, action research, and mixed-methods research to construct a teaching model centered on cultivating engineering thinking. Focusing on projects such as "The Blossoming Rapeseed Engineering," "Smart Upgrade of Campus Parcel Cabinets," "Support Frame Rescue Plan," and "Design and Assembly of Portable Table Lamps," a problem-based, project-oriented learning model was designed to nurture engineering thinking. This model was then implemented in the general technology classrooms of 12 ordinary high schools in W City, Zhejiang Province, including 4 first-level provincial key high schools and 5 third-level provincial key high schools. Over the course of 5 years, multiple rounds of action research were conducted to iteratively refine and assess the effectiveness of this approach.

In the first round of action research, the project-based learning (PBL) teaching model was introduced, giving rise to a "1 Context + 3 Questions + N Tasks" format within the Problem-Oriented PBL (POPBL) framework, where learning is guided by questions within a project context. Implementation revealed inconsistencies in objectives, assessment, and the process itself, and highlighted that students, when confronted with complex scenarios, often struggled to identify key issues — resulting in breadth but lacking depth in their understanding. Nonetheless, this model clarified the sequential linkages between contexts, questions, and tasks, thereby laying a foundation for subsequent lesson designs that strive for coherence among teaching, learning objectives, and assessment.

In the second round of action research, the Backward Design principles of Understanding by Design (UbD) and theories of Deep Learning were incorporated, referencing the 'Standards for Technology and Engineering Literacy : Defining the Role of Technology and Engineering in STEM Education.' Anchored in big ideas as primary competencies, sub-goals were defined, leading to a deeper excavation of question scaffolding within project-based learning. A triadic question support system was constructed, centered around student-generated questions, teacher-guided inquiries, and subject-focused problems, all aimed at directing students to enhance their engineering thinking through task engagement. An assessment continuum was also established, leveraging evaluation as a tool to facilitate student reflection and knowledge construction. However, the unique nature of engineering thinking, being elusive to quantify and articulate, persisted as a classroom challenge despite these advancements.

In the third round of action research, the focus shifted to making engineering thinking education more tangible and visible. Given that engineering education is project-based and steered by questions, a problem framework was utilized, integrating Problem-based Learning theories, to create a visual pathway for engineering thinking through question diagrams. This led to the development of a learning model that is "core-centered," "systematized," and "visualized," employing a question system specifically designed to cultivate engineering thinking skills in students. While this approach addressed several instructional design challenges, shortcomings in the thoroughness of problem system research resulted in practical implementation issues, such as deviations from learning objectives and prolonged time spent constructing core questions.

In the fourth round of action research, a target system centered on big ideas and higher-order thinking in technology and engineering was constructed, establishing links between core competencies and objectives related to knowledge and skills. This effort further refined the categorization of student questions within the problem system, comprising initiating questions grounded in project scenarios, generative questions that foster 思维 exploration, and reflective questions arising from productive failure. Consequently, a strategy for constructing core questions based on

student-driven inquiries was formulated. This essentially addressed the issues of engineering thinking being intangible and unmeasurable, as well as problems being broad but lacking depth.However, in classroom practice, the challenge remains of effectively leveraging the visualized problem system to facilitate efficient knowledge transfer, highlighting an area that urgently calls for resolution.

This study has laid the groundwork for the Project-based Learning approach aimed at fostering engineering thinking in students, utilizing a structured problem system as a support framework and employing visualization techniques to make the process of cognitive education more explicit. For future research, there is a need to further refine the problem system, explore various methods of visualizing the problem structure, and more thoroughly examine strategies for leveraging this visualization to enhance the transfer and application of engineering thinking skills.

Key Words: Technology and engineering education, Cultivating Engineering Thinking, Problem-Based Learning, Project-Based Learning, Problem Scaffold

The main theme for PATT41 is “K-12 technology and engineering education and student development”, inviting delegates to present original research and scholarship exploring axiological, epistemological, and ontological aspects of the subject.

The conference theme and sessions are organised under four strands:

STRAND 1. Promotion the awareness of technology and engineering in K-12 education;

STRAND 2. Characteristics and cultivation of technology and engineering thinking in K-12 education;

STRAND 3. Challenges in K-12 technology and engineering education;

STRAND 4. Pedagogical content knowledge and teaching strategies in K-12 technology and engineering education.

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