Design and Technology Education: An International Journal

29.2

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Book review

Editorial: Celebrating the 40th year of PATT conferences

Kay Stables, Goldsmiths, University of London, UK
Lyndon Buck, University of Southampton, UK

This issue of *Design and Technology Education: An International journal* is a rather special one, special because it is being published in the 40th year since the PATT conference and international PATT community was founded, and special because we have a Guest-edited Special Issue of articles developed from the 40th PATT Conference. (The PATT Acronym was created from the first ever PATT conference and stands for *Pupils Attitudes Towards Technology*). The use of the word 'pupil' gives the game away that conference papers presented focus mainly on schools education – research relating to design and technology education for those aged from 3 to 18 years. We are particularly excited by this special issue as it is a 'bumper' one, 21 research articles provided by authors from 9 countries across 4 continents, providing insight into learning and teaching from early years upwards. The Guest Editors, Sarah Davies, Matt McLain and Bhavna Prajapat both hosted the conference and produced this Special Issue and we thank them for their contribution! Check out their Guest Editorial to see the richness and variety of what is presented.

Looking back over the 40 years since that first conference in the 1980s, it is clear how much has changed both in the world and in education. Design and Technology education at all levels has massively evolved from traditional workshops and narrow silos of disciplinary focuses to a world that is fast moving, from the introduction of the internet to the likes of 3d printing and now the generative AI, becoming more interdisciplinary along the way.

With consideration for this shift, we are also pleased to have a review of *Design and Technology in your School: Principles for Curriculum, Pedagogy and Assessment.* The book is authored by HildaRuth Beaumont and Torben Steeg and is future facing but builds on their combined, more than four decades of experience to provide a vision to support and inspire current and future educators. The review is presented by Mark Norris, a UK Design and Technology school D&T Department Head and Lecturer in Education from the University of Sussex. Based on the breadth of his experience within both school and higher education settings he provides clear insight into the details in each chapter and highly useful insight into the value for both teachers and leaders of Design and Technology in schools, alongside the value of the book for student teachers just starting their careers.

Guest Editorial

Sarah Davies, Nottingham Trent University, UK
Matt McLain, Liverpool John Moores University, UK
Bhavna Prajapat, University of Brighton, UK

We are delighted to present a collection of 21 peer-reviewed articles in this Special Issue of the DATE journal from the 40th Pupils' Attitudes Towards Technology (PATT40) conference, hosted by Liverpool John Moores University between 31st October and 3rd November 2023. As guest editors, we also want to pay tribute to our colleagues on the conference committee and review panel as well as all of the delegates who made the conference a significant and relevant contribution to the international community of scholars in the field of Technology Education. Please take time to read the excellent contributions in the conference proceedings (Davies et al., 2023).

For those who are unfamiliar with the acronym, PATT is a conference series that originated in the Netherlands, named after a 1984 study to determine the attitude toward and concept of technology held by students aged 12-15 years. From then it has grown and flourished over four decades, and it is one of the longest standing research conference series. The conference has met every year but one; due to the 2020 COVID-19 pandemic. An academic institution hosts the conference in a different country each year, drawing together educators and scholars with an interest in design and technology education, in its broadest sense. Over the past six years PATT has been held in Athlone, Ireland (2018), Malta (2019), Rauma (2020, albeit online), Finland (2021), St John's, Newfoundland (2022), and Liverpool, England (2023) – having last been in the UK in 2011. This year PATT41 is being hosted in Nanjing, China, in October, then Montreal, Canada, in 2025, and Norrköping, Sweden, in 2026.

The PATT40 conference theme was *"Diverse Experiences of Design, Technology and Engineering Education for a Contemporary and Pluralist Society"*, which was chosen to help advance research on design and technology praxis that contributes to a quality experiences for children and young people on school systems and curricula around the world. Sub-themes were developed to capture the uniqueness, diversity and plurality of our subjects and the impact that they had on children and young people, and society. PATT is a longstanding conference series that is all about meeting and sharing as a community of past, present, and future researchers. We celebrate equality, diverse and inclusion, seeking to nurture early career research and foster a plurality of views and experiences.

We are proud of the fact that PATT40 was the largest PATT conference to date, in terms of numbers of attendees and presentations. Over the four days of the conference, we welcomed 138 delegates, with 78 papers and 13 academic posters being presented. Furthermore, it was a particular joy to welcome at least 16 practicing teachers (about 12% of the delegates), nine of whom were from schools in the UK. Delegates hailed from 19 different countries across five continents, bringing their insights to bear on local, national, and international problems and opportunities. From as far west from Liverpool as the United States of America and Canada and as east as China, South Korea, Taiwan and Japan. From Norway and Sweden in the north to

New Zealand and South Africa in the south. UK delegates only represented 29% of the attendees, so it was a truly international affair. What was particularly exciting was the number of teachers of D&T who attended, some of whom are undertaking postgraduate studies, some who presented research, and some who just wanted to hear the latest research being presented. We also had some of the most diverse research topics being presented, making it difficult to identify specific trends or themes, which indicates a thriving community of scholars stiving to explore and expand the knowledge base of our subjects.

Overview

To give a taste of what you will find in this Special Issue, we summarise each article below to entice you to read on and learn more about the latest research in the field. These articles have been developed and expanded from the approximately 3000-word original papers presented at PATT40 Liverpool in 2023. They have been double-blind peer-reviewed to ensure that they are rigorous and significant. However, as excellent as they are, to say that they are the best 21 offerings from the 91 presentations at the conference would do a great disservice to the esteemed colleagues who did not take up the invitation to turn their research into a 6000-8000-word article for this Special Issue. Some will have submitted to other excellent journals and others will have chosen to focus their efforts elsewhere. As guest editors, we salute PATT40 delegates, one and all! This issue is organised into four themes bringing together articles focusing on curriculum, design pedagogy, STEM pedagogy and technology enhanced learning.

Curriculum

This section has eight articles from five countries, exploring design and technology curricula in Germany, Japan, New Zealand, Sweden and the USA.

Martin Fislake and Jana Schumacher (University of Koblenz, Germany) report on the "Technikkiste" [Tech Box] project, launched in 2018, which aimed to promote STEM education in Rhineland-Palatinate primary schools by distributing metal construction kits. A 2023 evaluation revealed that only 70% of respondents were aware of the kits, and just 43% had used them in classrooms. Key barriers included insufficient kits, inadequate teacher training, and lack of time. Despite these challenges, teachers generally found the kits useful and expressed interest in receiving more. Recommendations for future projects include better communication, more training opportunities, and ensuring sufficient resources for effective implementation.

Ruth Lemon (Technology Education New Zealand) presents from her doctoral research at University of Auckland on the development and implementation of the Māori-medium Technology curriculum (Hangarau) in Aotearoa New Zealand. The study focuses on curriculum coherence and the integration of Indigenous knowledge in light of the challenges posed by Eurocentric influences and the need for alignment with Māori educational philosophies. The study draws on Ministry of Education archives and interviews with curriculum experts (mātanga). Key themes include the importance of language revitalisation, the integration of mātauranga Māori, and the need for localised curriculum development. The article recommends the need for greater governmental support, flexible curriculum design, and systematic research to enhance curriculum coherence and support Māori-medium education.

Deana Lucas, Greg Strimel and Vanessa Santana (Purdue University, USA) examine a polytechnic high school model that replaces traditional classes with industry-driven design projects, aimed at preparing minoritised urban youth for college and careers. This model emphasises integrated STEM learning through real-world problem-solving. From the surveys and focus groups with students, teachers, and alumni their analysis reveals that whilst this model enhances 21st Century skills and a sense of belonging, it faces challenges in traditional academic preparedness, particularly in mathematics. Their recommendations include balancing innovative learning with structured academic instruction and improving communication between high schools and universities to better support student transitions to higher education.

Jun Moriyama (Hyogo University of Teacher Education), alongside nine coauthors from across Japan, report on the development of a new framework for technology and engineering education by the Japan Society of Technology Education (JSTE) to promote STEAM education in the country. They surveyed 1,656 junior high students, finding positive attitudes towards technology classes and identified a lack of exploratory activities and problem-solving skills. The new framework emphasises a triple-loop model for engineering design, integrating physical and cyber technologies, and a STEAM learning model centred on engineering. The framework aims to enhance technological innovation and governance abilities. A survey of JSTE members showed general agreement with the framework, leading to its finalisation with some revisions.

Hisashi Nakahara (Oita University), Keita Sera (Nara University of Education), Tetsuya Uenosono (Hirosaki University), Atsuhiro Katsumoto (Hokkaido University of Education) and Jun Moriyama (Hyogo University of Teacher Education) examined Japanese junior high school students' perspectives on improving products and their user perceptions after materials processing technology lessons. A survey of 721 students revealed high engagement in practical tasks, with 91.7% enjoying making things. However, only 41.5% saw these experiences as beneficial for future careers. Students focused on safety (45.2%) and functionality (34.4%) in product improvements, often neglecting environmental and economic factors. Differences in user-oriented improvements suggest that descriptive reflection enhances safety awareness. The study highlights the need for curricula that link technological learning with career opportunities and incorporate societal and environmental considerations that connect with real opportunities of problem solving.

Per Norström, Susanne Engström and Birgit Fahrman (KTH Royal Institute of Technology, Sweden) write about how to ensure technology education remains relevant over time. They highlight the challenge of predicting future technological needs and the tendency of curricula to use vague descriptions to stay timeless. Interviews with Swedish teachers, teacher educators, and students revealed a focus on timeless skills like engineering design, problem-solving, and basic programming, rather than specific factual knowledge. The study emphasises the importance of fostering curiosity, critical thinking, and a positive attitude towards technology. It concludes that teachers play a crucial role in making technology education future-proof, despite limited guidance from curricula.

Maria Sundler, Ellinor Hultmark, Susanne Engström, Helena Lennholm and Annica Gullberg (KTH Royal Institute of Technology, Sweden), explore secondary school students' conversations about product life cycles and sustainable development. The article reveals that students discuss all three dimensions of sustainability (social, ecological, economic) but focus on different life cycle phases for each dimension. Social aspects are linked to production, economic aspects to usage and transportation, and ecological aspects that span all phases. Students often view sustainability through anthropocentric and technocentric lenses, emphasising human-centred and technological solutions. The study offers practical solutions to enhance students' understanding of sustainability's complexities through the use of deliberative conversations that foster critical thinking and informed decision-making.

Alexina Thorén Williams, Maria Svensson and Dawn Sanders (University of Gothenburg, Sweden) use collage inquiry to understand primary teachers' perceptions and experiences of forests and urban areas in Sweden. The collage inquiry revealed teachers' emotional connections, perspectives, and curiosity about these environments, categorised into three themes: temporarily situated, place dependent, and emotionally connected. The method highlighted the importance of reflection and emotional engagement in teaching sustainability. The findings suggest that understanding teachers' relationships with natural and urban environments can enhance their ability to teach sustainability, bridging ecological and technological systems for a more integrated approach to education.

Design Pedagogy

This section has five articles from four countries, exploring design and technology curricula in Germany, the Netherlands, Sweden, the UK and the USA.

In their article, Anne-Marie Cederqvist and Per Högström (Halmstad University, Sweden) explore how to prepare student teachers to integrate sustainability into technology education. They highlight the need for deep technological knowledge, understanding the relationship between technology and sustainable development, and fostering critical thinking skills. Inner qualities like confidence, empathy, and creativity are essential, alongside pedagogical knowledge to teach these concepts effectively. The study emphasises a multifaceted approach, combining personal values, pedagogical competence, and transformative teaching practices to equip future teachers with the skills and attitudes necessary for promoting sustainability in technology education.

The article from Jeanna (Snjezana) de Haan-Topolscak, Merle Ebskamp and Pauline Vos-de Tombe (Technische Universiteit Delft, The Netherlands) describe how Dutch STEM secondary school students and teachers understand the concept of a 'model' in the Research and Design (R&D) curriculum. They reveal confusion among both groups, with varying definitions and interpretations of 'model'. The study is situated within a curriculum that emphasises real-life design problems and interdisciplinary learning and the findings highlight the diverse nature of R&D teachers, who often lack design knowledge. The study calls for a unified understanding of 'model' to ensure consistent and effective teaching. Their article suggests that collaborative learning and shared experiences among teachers could improve conceptual clarity and teaching practices in R&D education.

Dani Hamade, Jan Landherr and Peter Röben (Carl von Ossietzky University Oldenburg, Germany) discuss integration of a design-oriented approach to robotics education in Germany. The paper emphasises the importance of allowing students to design robots for self-set goals. Their study highlights the limitations of traditional methods that only use robots as tools for interactive learning. The authors use the paper to propose an innovative methodology that encourages students to engage with the design elements of robots, enhancing their understanding of both theoretical concepts and practical applications. Initial examples from design-oriented robotics education events delivered through the authors University, show how this pedagogical approach can be used to encourage student technology teachers to develop their critical thinking skill and planning for innovative curriculum strategies in school.

Ellinor Hultmark, Susanne Engström and Annica Gullberg (KTH Royal Institute of Technology, Sweden) investigate teachers’ scaffolding strategies in relation to students’ verbal reasoning during the design process in Swedish secondary school technology education. Using sociocultural theory, they identify two reasoning types: means-end and cause-effect. Data from classroom observations and interviews reveal that teachers employ strategies of decreasing and increasing control, depending on the reasoning type. Decreased control involves questioning to encourage student thinking, while increased control uses instructive methods for specific guidance. The findings highlight the importance of teacher-student interactions in facilitating reasoning and learning in the design process.

Phil Jones, a teacher at Upton Hall School and doctoral student at Liverpool John Moores University in the United Kingdom, investigates integrating design thinking into the lower secondary school design and technology curriculum to foster 21st Century skills alongside subject-specific knowledge. Conducted with 12-13-year-old students in the North West of England, Phil highlights the importance of balancing knowledge and skills in education. The Design Thinking Integrated Learning (DTIL) model engages students in empathetic, creative, and analytical processes through real-world problem-solving. Findings suggest that this approach enhances creativity, collaboration, communication, and critical thinking, preparing students for complex future challenges. The study advocates for a curriculum that values both academic knowledge and practical, human-centred skills.

STEM Pedagogy

This section has five articles from four countries, exploring design and technology curricula in Canada, Germany, Sweden and the USA.

Brahim El Fadil and Ridha Najar (University of Quebec, Canada) explore the integration of STEM activities in education in their article, focusing on teaching variables and functions through practical applications like pendulum experiments. They highlight the importance of innovative pedagogical approaches, combining cognitive and social constructivism with technological tools such as virtual labs. The study demonstrates how STEM activities can enhance students' engagement, motivation, and understanding of abstract mathematical concepts. The findings suggest that hands-on activities and virtual labs foster critical thinking and problem-solving skills, underscoring the transformative potential of integrating STEM education with real-world applications.

Caroline Forsell (KTH Royal Institute of Technology) and Per Westerlind (Kunskapsgymnasiet – translation: Knowledge High School) explore students’ understanding of mechanical stress and strain using a digital interactive lab setup. Conducted with 107 Swedish upper secondary school students, they revealed that the teacher’s role was crucial for fostering learning. While digital aids were safer, they were also less impactful. Thematic analysis identified six groups based on students’ knowledge before and after the virtual and teacher lead lab work. A significant difference in learning outcomes was linked to improved learning for the teacher and class. The study concluded that while digital tools can aid learning, the teacher's influence remains paramount, especially in practical tasks involving complex concepts like mechanical stress and strain.

The study by Anna Perez (Linnaeus University), Maria Svensson (University of Gothenburg) and Jonas Hallström (Linköping University) investigates Swedish student teachers' perceptions of teaching programming in technology education for grades 4-6. Using a phenomenographic approach, they identify four categories of perceptions: following instructions in a logical order, learning a programming language, solving technological problems, and understanding and describing a technological environment. The findings highlight the need for student teachers to develop a deeper understanding of programming beyond basic instructions, emphasising problem-solving and the broader societal context. The study underscores the importance of integrating subject didactic knowledge with practical and conceptual understanding to effectively teach programming in technology education.

Franz Schröer, Claudia Tenberge, Nele Schemel, Malin Osnabrügge and Lea Schneider (Universität Paderborn, Germany) examine the integration of robotics into primary education to enhance teacher professionalization and inclusive technology education. It highlights the importance of combining theoretical knowledge with practical application in teacher training. Using learning robots like BlueBot™ and microcontrollers like Calliope mini™, the study demonstrates how these tools can foster computational thinking and problem-solving skills in students. The research underscores the need for a spiral curriculum that builds on students' prior knowledge and adapts to their learning needs. It also emphasizes the role of teachers in creating inclusive, engaging, and effective learning environments.

Marten Westerhof, Colm O'Kane and Gavin Duffy (Technological University Dublin) continue the flow of spatial literacy research coming out of Ireland in recent years. They describe using origami in an after-school makerspace to develop spatial literacy in primary school children. They argue that it is a crucial skill for STEM success, involving visualising, reasoning, and communicating about spatial relations. The article reports that the workshop allowed children to practice these skills creatively, with varied success - some struggling with diagrammatic instructions but engaging better with video tutorials. The study highlights the importance of spatial skills, knowledge, and self-beliefs. It calls for further research to define spatial literacy norms and develop pedagogical strategies to support children's spatial skills in maker education.

Technology Enhanced Learning

This section has three articles from three countries, exploring technology enhanced learning in design and technology, from Germany, Norway and Sweden.

Johan Lind (Malmö University, Sweden) explores how virtual reality (VR) images and verbal interactions support primary students' understanding of the nature and history of technology. Using VR in a classroom setting, students aged eight and nine demonstrated knowledge across all dimensions of technology, including its historical aspects. The findings suggest that VR images promote exploratory conversations and deeper comprehension of technological development. The study highlights the importance of teacher guidance and signalling in enhancing students' engagement and understanding. This approach can help teachers plan effective technology education activities that integrate historical perspectives and interactive learning.

Tore Andre Ringvold, Ingri Strand, Peter Haakonsen and Kari Saasen Strand (Oslo Metropolitan University, Norway) explore how AI text-to-image generators can transform design education. Their article highlights the potential for AI to democratise idea visualisation, enabling those with limited artistic skills to create professional-quality images. The study emphasises the strengths of AI as a catalyse to stimulate creativity through the provision of visual aids that have the potential to generate diverse design ideas. However, the authors highlight some of the challenges associated with digital bias, ethics, and the risk of reducing traditional motor skills in learners. The article calls for educators to develop digital competencies and critical thinking skills to effectively embed AI into their teaching.

Tobias Wiemer and Marius Rothe (Carl von Ossietzky Universität Oldenburg, Germany) tackle the use of Augmented Reality (AR) in industry and technology education, highlighting its potential and challenges. They propose that in industry AR enhances production efficiency, safety, and training, and in education it can improve learning outcomes but faces barriers like high costs, lack of resources, and insufficient training materials. An exploratory study among teachers in Lower Saxony revealed that while AR is seen as beneficial, its implementation is hindered by these challenges. The article calls for targeted research and development to create cost-effective, user-friendly AR applications and comprehensive teacher training programs.

Summary

The 21 articles in this special issue draw together research and scholarship from ten countries and five continents, exploring issues that have intrigued the design and technology education community for decades, like how to teach design, to new technologies such as AR/VR and Gen-AI. The collection portrays a vibrant research culture around the world, grappling with thorny issues and changing social and technology circumstances.

As guest editors, we strongly encourage classroom teaches engaged in design and technology education to scan through the titles, abstracts, and key words, to find intriguing hints and titbits. Once you have found an article or two that interests you, jump to the conclusions to see whether your interest is warranted, before diving in and reading the full paper. There is enough in this Special interest to satisfy your curiosity, whether you lean more towards the STEM side of design and technology or towards the arts and design. Keep the subjects alive by engaging with contemporary research insights and sharing them with your colleagues. And you might even be tempted to contact one of the authors to engage with your own research. Farewell, and enjoy!

Reference

Davies, S, McLain, M., Hardy, A. & Morrison-Love, D. (Eds) (2023). *Proceedings of the 40th International Pupils' Attitudes Towards Technology Conference*, 31 October-3 November, Liverpool John Moores University, Liverpool, UK. https://doi.org/10.24377/PATT40.2023

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Five Years of Construction Kits in Primary Schools: Evaluating the Current State of a Project to Facilitate Technology Education

Martin Fislake, University of Koblenz, Germany
Jana Schumacher, University of Koblenz, Germany

Abstract
In March 2018, metal construction kits were distributed to all elementary schools in Rhineland-Palatinate as part of the project called "Technikkiste" [translation from German: technology box] to promote STEM education. At the end of the year 2018, three more expansion sets followed. So far, no requests have been made to schools, even after five years of the project's start as to how and whether they use this material. Therefore, an evaluation study was carried out in 2023, which was intended to find out the current usage behaviour with the kits as well as to get an impression of the teachers regarding the in-service training that took place as part of the project. For that 921 elementary schools were asked to participate in an online survey. 69 answered the questionnaire some more gave informal feedback. The results from the survey already show that only about 70% of the responders are even aware of the metal construction kits. Around 30% stated, that they were not familiar with the metal construction kits. In addition, only about 43% of the participants indicated that the kits have ever been used in the classroom at their school. One of the main reasons why they do not use the constructions kits is that the school has allegedly not received a kit or has too few for classroom use. This brief excerpt from the survey results already shows that the promotion project is not showing the success that the Ministry of Education had hoped for.

Keywords
Construction kits, Primary schools

Introduction
Against the lack of technology education in schools and the resulting consequences, projects are occasionally initiated to combat these resulting consequences (VDMA, 2019), which at least give the impression that education policy wants to change this. So this is was what was done by the Ministry of Education of the federal state of Rhineland-Palatinate in Germany. With the aim of stimulating more interest in STEM topics at elementary schools it initiated a support program named "Technikkiste". It was based on the findings from socialization research, according to which construction kits and other technical toys were often among the decisive motives for a technophile career and subject choices in previous generations (acatech, 2009).

However, despite the associated financial and logistical effort and individual accompanying measures such as further in-service training, no evaluation has taken place even five years after the start of the project. But, because such an evaluation study can provide a wide range of insights and consequences for teacher training, everyday school life and future support programs, this study was intended to investigate whether and, if so, how the metal construction kits are still being used in schools. Consequently, questions arose as to what has become of the metal construction kits in the meantime and how teachers reflect on them? Specifically, the aim is to find out whether the construction kits are still being used and, if so, to what extent and in what settings? Another aim was to find out whether all schools have received these kits at all and how satisfied the teachers are with the materials and the training opportunities.

In 2018, the Ministry of Education in Rhineland-Palatinate launched the "Technikkiste" project to promote STEM education in a classical way. For this purpose, a metal construction kit (see Figure 2) was sent to each elementary school together with prepared didactic recommendations for use and one more kit if at least one teacher participated in an in-service training (Tschiedel, 2023). A total of 355 teachers decided to participate in this in-service training. Five years later, the question arose: how are these boxes being used today and what feedback can teachers provide to the ministry? For this reason, a study was developed in July 2023 and all 921 elementary schools in Rhineland-Palatinate were invited to participate. In addition, recommendations for future support programs were to be derived from this.

Related Work

For a study that deals with the use and retention of construction kits as a means of promoting STEM interests in a project, it is obvious to consider research that is focused on construction kits as such, deal with their basic mechanisms of action on the target group and, on the other hand, include results that examined the STEM promotion projects themselves.

While a lot of historical and cultural driven research about construction kits like those of Leinweber (1999) and Noschka and Knerr (1986) is available, those about their use as educational tool is slightly limited. However, Sachs and Fies (1977); Fast (2006, 2008) and Plickat (2006) have already elaborated the possibilities of construction kits used in the German classrooms for technology education. Continuing that, Fislake (2022) summarized the history of construction kits as educational tools at all, beginning with Fröbel’s Spielgaben. He outlined that these Spielgaben are one of the first known construction kits and still used as educational tools in Kindergardens. Later, MECCANO and other construction kits conquered family homes in western cultures before they first entered classrooms in the nineteenth century (Jaffé, 2006). One of their characteristics was the causal relationships between the effects of teaching and playing scenarios appears to be self-evident on the basis of assumptions, experience and plausibility.

Today, scientific evidence of connections between interventions with construction kits, socialization processes, habitus acquisition and career entry is sought on the basis of empirical data. According to van Tuijl and van der Molen (2016), retrospective life course research plays a significant role here due to the time spans to be considered, as Helwig (2003) did in his longitudinal study with children aged 7 to 17. Accordingly, van Tuijl & van der Molen (2016) characterize professional development as a lifelong process and childhood as an important formative time for this. Papadakis et al. (2021) emphasizes it and rate early childhood (from birth to age eight) as a crucial period for children’s development and rate positive key experiences as one of the most prevalent factors, to initiate interests towards technology. Acatech (2009) further shows that early technical socialization is one of the decisive factors for a later orientation towards STEM professions.

Pfenning et al. (2002) and Ziefle et al. (2009) extend this approach and refer to studies from empirical social research, according to which successful engagement with scientific and technical topics requires a combination of interest, motivational dispositions and cognitive abilities. As a result, technology socialization is considered as an important prerequisite for choosing a corresponding STEM occupation.

In addition to these aspects acatech also studied the effects of projects to promote technology-related topics. It was supplemented by an inventory of all school and extracurricular STEM promotion projects, of which only 21.2% were aimed at children of primary school age (acatech, 2008). As one of the projects analysed, the private project "Denzlinger Cleverle" has the particularity that the children are very motivated to participate and even enjoyed gaining new experiences with technical devices in their free time. Two reasons for this success could be the close mentoring and the open-ended tasks. Because this project is not based on a well-designed pedagogical concept, but has a high practical component, it can be categorized as autodidactic self-education from a didactic perspective. In addition, children in a fear-free environment are cognitively and motorically able to use electrical and technical devices with caution, which makes the low number of STEM promotion projects for elementary school children unfounded. In the final report, the project is described as a "very inspiring, ambitious model project" that operates "at a high level for support and equipment" (acatech, 2010).

Another project is called “KiTec - Kinder entdecken Technik” [translation from German: KiTec - Children discover technology] and aims to encourage children to work independently and in a solution-oriented manner on their own ideas. The aim is for them to get in touch with their technical skills and experience the importance of technology (Wissensfabrik Deutschland, 2023). The “Wissensfabrik” (transl.: Knowledge Factory) provides the appropriate course materials needed and offers suggestions for embedding the teaching units. Each of the material sets consists of three boxes containing tools and construction materials.

However, the acatech study was just as critical of the teachers' limited experience with tools as it was of the children's "increasing lack of manual experience in handling traditional technical instruments and construction materials" (acatech, 2011). In addition, free experimentation and the associated need for assistance was identified as a reason why some teachers were deterred from using the boxes.

Project ‘Technikkiste’ to Facilitate Technology Education

With the aim of stimulating more interest in STEM topics at elementary schools, the "Technikkiste" program was initiated by the Ministry of Education of the federal state of Rhineland-Palatinate, Germany. The project is based on findings from socialization research, according to which construction kits and other technical toys were often among the decisive motives for a technophile career and choice of field of study in previous generations. According to Tschiedel (2023), at the start of the project in March 2018, one construction kit was sent to each of the 961 elementary school in Rhineland-Palatinate, which could be supplemented with a further kit for each school if a teacher took part in further teacher training. In November 2018, additional extension sets were also sent to all elementary school (Tschiedel, 2023), resulting in the distribution of over 4,000 metal construction kits worth €263,000, including the 131 schools for children with learning difficulties and a spare parts service. During the preparations, a five-page teaching handout was drawn up and sent digitally to the schools at the end of February 2018 (Hubig, 2018). Above all, it was intended to provide information about the various possible uses and applications.

Figure 1. Training locations together with the number of schools in each school district. (Schumacher, 2021)

In addition to a didactic and methodological classification, the handout also shows possible applications for lessons in the morning, as well as in the afternoon programs of all-day schools. A separate chapter describes the initiation of technology-specific ways of thinking and acting and highlights their advantages.

Between March 2018 and March 2019, accompanying training courses were offered at 14 dates and twelve different locations (see Figure 1) to support the teachers. In order to achieve an equal regional distribution, the training locations were offered in as many regions as possible and attended by a total of 355 teachers, as Holder (2023) explained.

The content of the training included an introduction to the topic and the link to the curriculum, as well as various application and possible teaching methods. In addition, the participating teachers were given specific closed and open tasks to try out the metal construction kits. Finally, a link to practice was established by the participants developing a word memory with technical terms, cognitively activating task formats and a meaningful structure for the workplace (Holder, 2023).

The basic construction kit is called type C166 (see Figure 2) and comes from the eitech company. It consists of 527 small parts mostly metal, a few made of plastic and is contained in robust wooden boxes (eitech, 2023). The electric and solar expansion set contains additional 135 components, the gear set another 250 parts. Suitable tools such as screwdrivers and illustrated step-by-step building instructions that show how to build eleven different models of varying degrees of difficulty were also included (Tschiedel, 2023).

Figure 2. Basic construction kit type C166 von eitech (eitech, 2018)

One of the main arguments for choosing and using the eitech construction kit was the positive experience from the ‘Kleine Konstrukteure’ (transl.: little constructors) as part of the extracurricular summer school called technikcamps (transl.: technology camps) which is based on basics on the training of pre-service teachers for technology education and is distributed by the University of Koblenz (Fislake, 2022). In the vacation courses offered there, children from the age of 6 can gain their first experience of technology in a playful and independent way.

The enclosed building instructions make it easier to get started, offer a systematic approach and encourage spatial imagination. The necessary handling of the tools train fine motor skills and the assembly of the components requires patience and perseverance. In addition, the construction kits offer the freedom to realize one's own creative ideas, as the fire engine shown in Figure 3 demonstrates. It was designed and built by a 7-year-old without instructions. It is remarkable how the boy installed the light on top of the vehicle, with a functioning electrical circuit, independently by trial and error.

Figure 3. Fire engine of a second grader. Built with the basic and extension kit. (Schumacher, 2023)

Research method

An online questionnaire was selected and developed as the evaluation instrument for the planned full survey of all 921 public elementary school in Rhineland-Palatinate. The decision was made because it appeared to be an efficient means and at the same time offered the possibility of achieving results that were as representative as possible (Aeppli, Gasser, Gutzwiller, & Tettenborn, 2016). The people who accepted the invitation were able to take part in the survey anonymously and in compliance with data protection regulations in summer 2023. Although topic-centred interviews with a smaller sample were discussed as a supplement or as an alternative type of survey, they were rejected.

The questionnaire contains 29 questions (items) with single and multiple possible answers as well as free text fields. It is divided into six thematically different dimensions, each containing two to five items. As the questions build on each other and partly follow an if-then scheme, not all participants had to response to every question. In addition, due to administrative requirements, participants were free to decide whether they wanted to answer any of the questions at all. As a result, the items without an answer were scored differently than those with the answer "no answer".

Results

Of the 921 invitations sent out, 69 people completed the questionnaire. This corresponds to a response rate of 7.5%. In addition, five schools submitted written feedback by email. Around

70% of participants stated that they were familiar with the metal construction kits. Only 1% selected neither yes nor no and therefore left the field unanswered.

Figure 4. results of item 2

When asked about the number of kits received, 30% stated they did not know the number. One did not answer, while 17.39% responded 0 or 2 kits. 12% received one kit, while 8.7%, reported 5 or more, 7.2% got 4 and only 5.8% got 3 kits (see Figure 4).

When asked how many extension sets were received, around 38% responded "I don't know". 32% said that their school had not received any extension sets, while five participants said that they had received one extension set each. For 2 sets there are three people, for 3 and 4 sets there are four responses each. Two respondents left their answer option unanswered.

For question 4, the number of metal construction kits currently available could be estimated if the number was not known. With 30.2% the largest proportion stated that their school currently had two complete sets. 25.4% responded that there was no basic construction kit at their institution, which is illustrated in

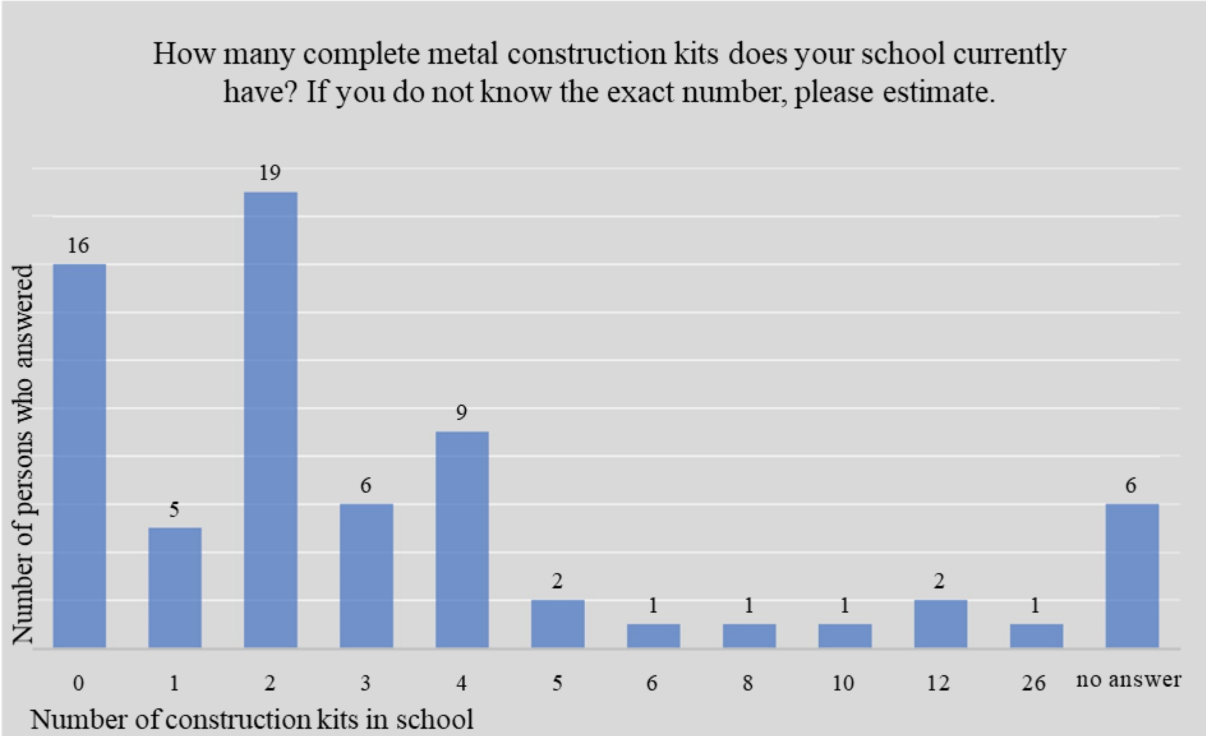

Figure 5.

Figure 5. results of question 4

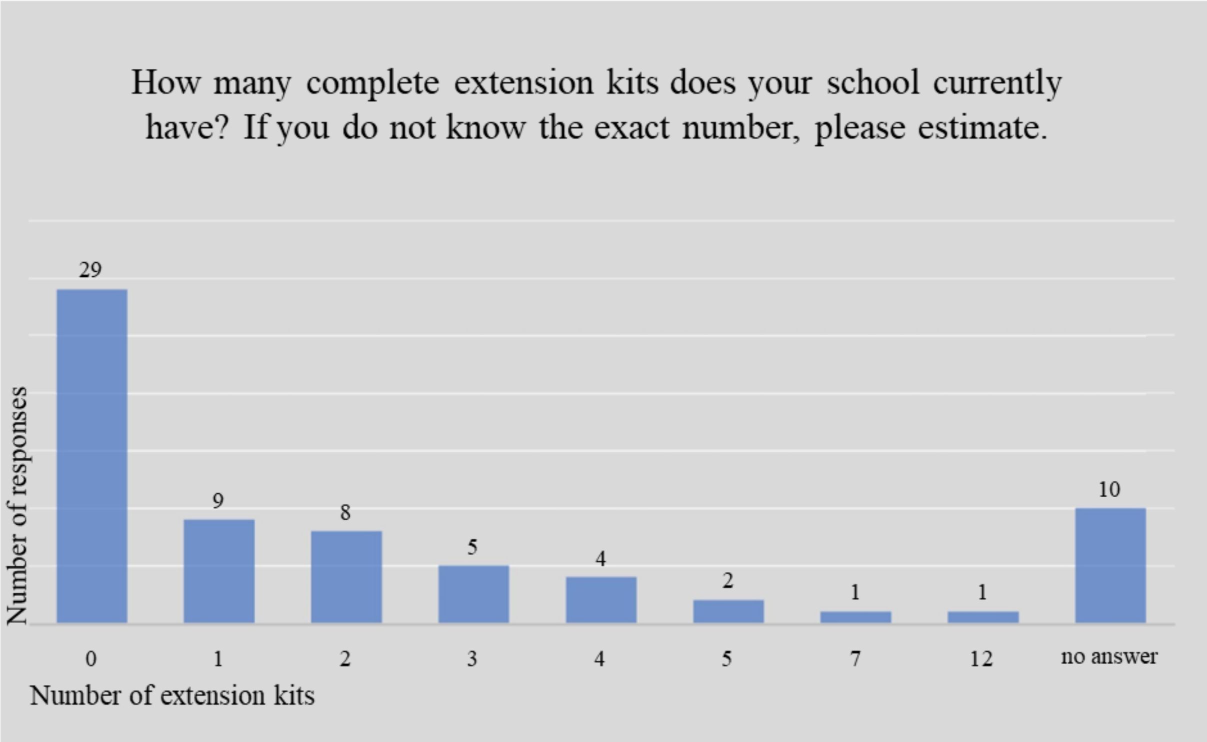

Figure 6. results of item 5

As can be seen in Figure 6 question 5 revealed that the schools currently have an average of 1.2 complete sets in use, although on average each elementary school should have 2.8 complete metal construction kits. Around 42% stated that their institution does not have any additional kits.

Furthermore, around 37% of respondents reported to question number 6 that the kits they received never have been used in lessons at their school. For the same question, 30 out of 69 people answered "yes" and 13 people said "no answer".

Around 34% did not react to question 7, placing them in the "unanswered" group. Around 18% use the metal construction kits once or twice a year. Eleven out of 69 resondents described their usage behaviour as "sporadic". Around 11.6% never use the construction kits, as illustrated in Figure 7.

Around 11.6% selected the "no response" option, while four opted for the frequency of use "every 2-3 months", which corresponds to around 6%. One stated that they use the metal construction boxes weekly. None of the participating teachers use the technology box on a daily basis.

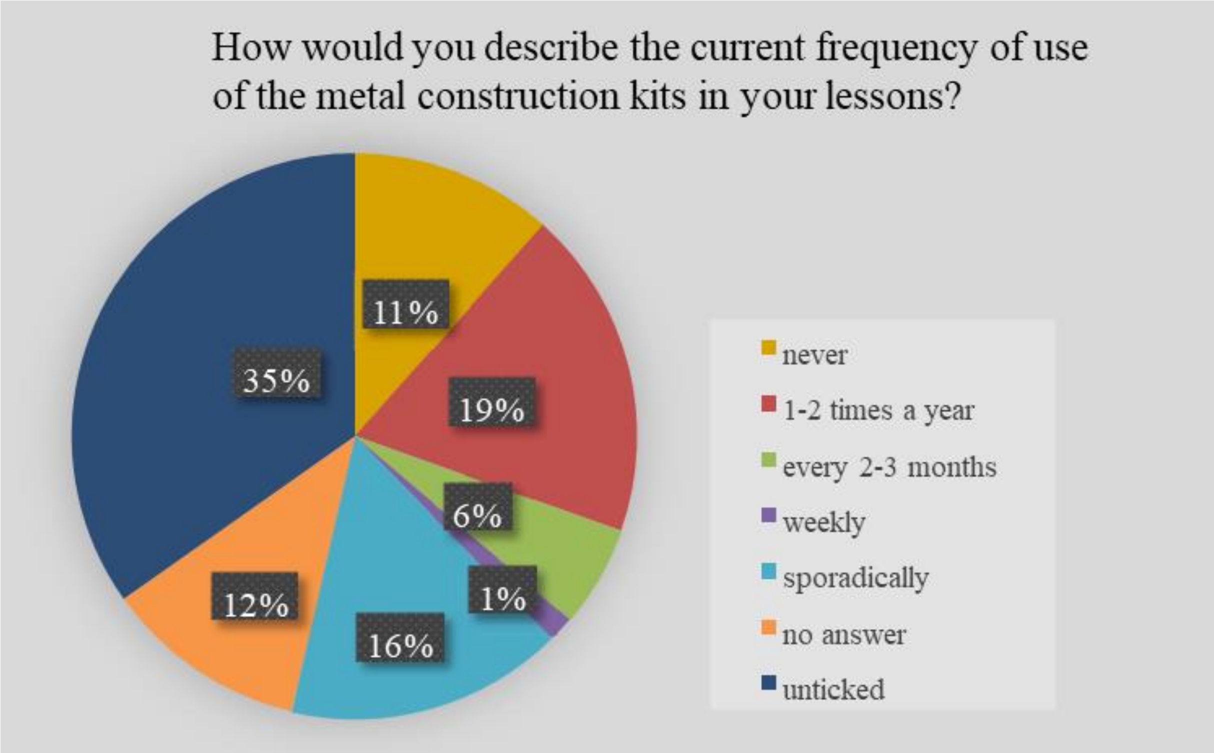

Figure 7. results of question 7

The reasons for not using the kits can be summarized as follows: 20.3% had not received any boxes. Another 20.3% stated that they had too few boxes for optimal use and that the school budget for additions was often insufficient. 13% cited lack of time as a reason for not using them or argued that it was more important to promote basic skills. Six people gave this reason. Four teachers mentioned a lack of teachers as the reason, as a second teacher would be needed for use in lessons. Four participants responded that the boxes were not usable due to incompleteness. A similar argument is that the number of boxes is not compatible with the group size in their classes. Two people emphasized that the number of children in their classes were too high or that the school had too few boxes. Three people also stated that the instructions were too complex for children and that they could only be used without problems from K 4 onwards.

Two teachers criticized the usability of the metal construction kits, as the following description shows: "It is a problem to keep the kits complete. When working with a class, it is difficult to keep an overview. Children also bend the flat bars very quickly - they are also very unstable." (translated by authors). Other individuals provide arguments such as (translated by authors):

- "The purchase came top down and was not supported by anyone in the school. Like so many ideas that come from the Ministry of Education."
- "No instruction. No personal interest."
- "Hygiene measures in Corona time. Use in first and second school year does not seem promising. One colleague has the boxes permanently in her classroom for free construction."
- “Lack of willingness on the part of teachers to deal with the topic.”
- "It takes a long time for the children to build a model."

- "Our textbooks are not tailored to this. I therefore forgot about the boxes and think it's good to be reminded by this survey. There were so many other important and interesting topics. As a teacher, it's easy to stay on familiar tracks."

Nevertheless, a third of the surveyed completely agreed with the statement of question 9: "I consider the use of the metal construction kits during lessons to be useful." Almost as many voted "somewhat agree" and around 13% responded "somewhat disagree". Just under 6% did not agree with the statement at all, while 11 respondents did not provide any information.

When asked to assess the use of the metal construction kits as a self-learning object, a third of the participating teachers tended to agree. In contrast to question 9, only 23% fully agreed with the statement in question 10. 13% responded that they somewhat disagreed with the statement. One person did not agree with the statement at all. Ten out of 69 participants selected "no answer". Question 11 asked for feedback about the usefulness of the kits as a simple activity material. 31.8%, or almost a third tended to agree with the statement "I consider the use of the metal construction kits as an activity material to be useful". 18 people agreed while 23.2% rather disagreed with the statement. Five teachers did not consider the kits to be useful as an activity material at all, while around 12% chose the "no answer" option.

A third of all respondents stated (see Figure 8) that they had neither received nor read the five-page teaching handout for action entitled “Technikkiste – Unterrichtsmaterial zur Förderung des naturwissenschaftlich-technischen Lernens in der Grundschule“ (transl.: "Technology box - teaching material to promote scientific and technical learning in elementary school". In contrast 26% answered that they had received and read the recommendations for teaching. The same number of people did not wish to answer this question. Around 15% of the participating teachers chose the answer option that they had received the handout but had not read it.

Around 30% did not want to answer question number 13 on whether they had received ideas from the handout regarding the use of the construction kits. A further 34% left this question unanswered. In each case, around 13% received no or only partial ideas for the use of the metal construction kits from the handout. However, six people answered "yes" to this question.

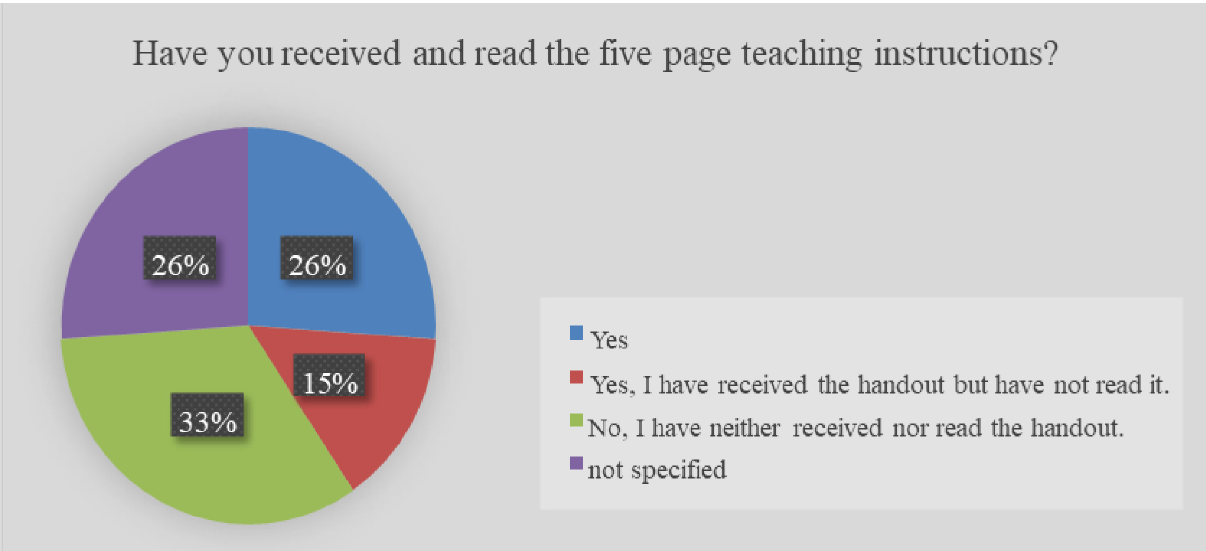

Figure 8. results of question 12

In question 14, the following ideas for using the metal construction kits were collected, with nine out of 69 participants giving the following answers (translated by authors):

- "As a study group in afternoon classes"
- "Our technology kits are used exclusively in a "construction" study group one afternoon a week. Here we still build with old fischertechnik construction sets, but also with materials such as wood, cardboard and paper."
- "Building vehicles and using small tools. Topic is covered as a compulsory subject in subject lessons in year 3 or 4 for project days/project weeks/study groups" (Answer was given twice.)
- "Individual electricity projects"
- "I was only able to try out the kits on a Discovery Day. There, the children built various vehicles according to a plan."
- "Within the topic of energy generation, stability and balance, etc., these construction kits deepen certain technical knowledge."
- "Installation in science lessons with experiments on propulsion and movement"

Only 19% out of 69 people took part in the teacher training offered. 8.7% did not give a reason. In contrast, 41 persons gave reasons for not taking part in the training, which corresponds to 59.4%. The most common reason was lack of time due to family circumstances, such as childcare or staff shortages, as described by the following answers (translated by authors):

- "Too little time, as there was a lot of additional work due to teacher absences"
- "As a head teacher and class teacher, I often don't have enough time. As we are a small, single-form entry elementary school without a reserve of substitutes, we can't guarantee further training without lessons being cancelled."

Nine people reported that they had not received any information about the training program. In addition, six people stated that they considered other topics or other training courses to be more important to them and had not taken part for this reason. Four participants explained they were not yet in the teaching profession at the time of the training. Two people made already their own experiences with the kits and did not consider it to be very practicable and therefore did not take part. Only one other teacher said that she was familiar with the boxes and did not need further training to use them.

For question 17, 13 respondents explained their reasons in writing, with similar statements being summarized below. Eight people described that their personal interest in technology, science or STEM education in general had motivated them to register. Only two people wrote that receiving another kit would have motivated them to take part. Two other people argued that they hoped the training would give them more ideas for using the construction kits in the classroom. Other reasons that were occasionally given were (translated by authors):

- "Interest and own inclination to work with haptic technology and to encourage the children in things like problem-solving skills and creativity."
- "I'm a counsellor myself and conducted the training at school."
- "Proximity and cooperation"
- "- wanted to try something new"

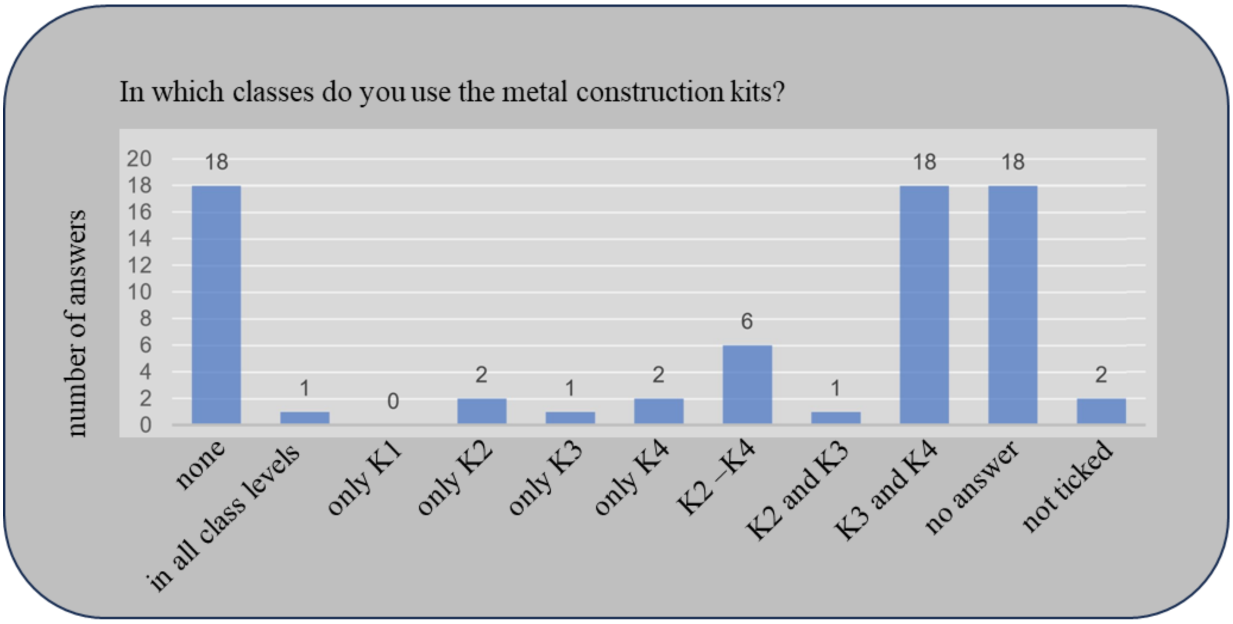

Figure 9. results of question 18

Question 18 was used to record the class levels in which the construction kits were used. According to this, 26% do not use the metal construction kits at any grade level. Just as many use the construction kits in 3rd and 4th grade. A further 26% did not specify. Six people selected grades 2 to 4. Only one teacher uses the technology box in all grades. No one uses the technology box only in first grade, as can be seen in Figure 9.

The exclusive use in the second class is the case for two teachers. Another person stated that they only use the box in year 3. Another teacher combines grades 2 and 3. Two respondents stated that they only use the construction kits in grade 4. The question was also left without an answer by two people. Around 26% declared that they do not use the kits in any setting while 30% responded only use the metal construction kits in the mornings during lessons. One teacher stated that they were used exclusively in the after-school care program. The kits are also used in the afternoon, but in the form of a working group at an all-day school, by 7.25% of respondents. Three people selected the combination of "in the morning" and "after-school care". Four teachers stated a variation of "mornings" and "working group" while two used them in the after-school care program and in a working group. Some 20% selected "no answer" and one person left the question unanswered. About 30% only use the engineering construction kits in subject-specific lessons, which means that for the majority of respondents it is the sole area of use. Three people use the construction kits in both mathematics lessons and Sachunterricht [Translation from German: general science].

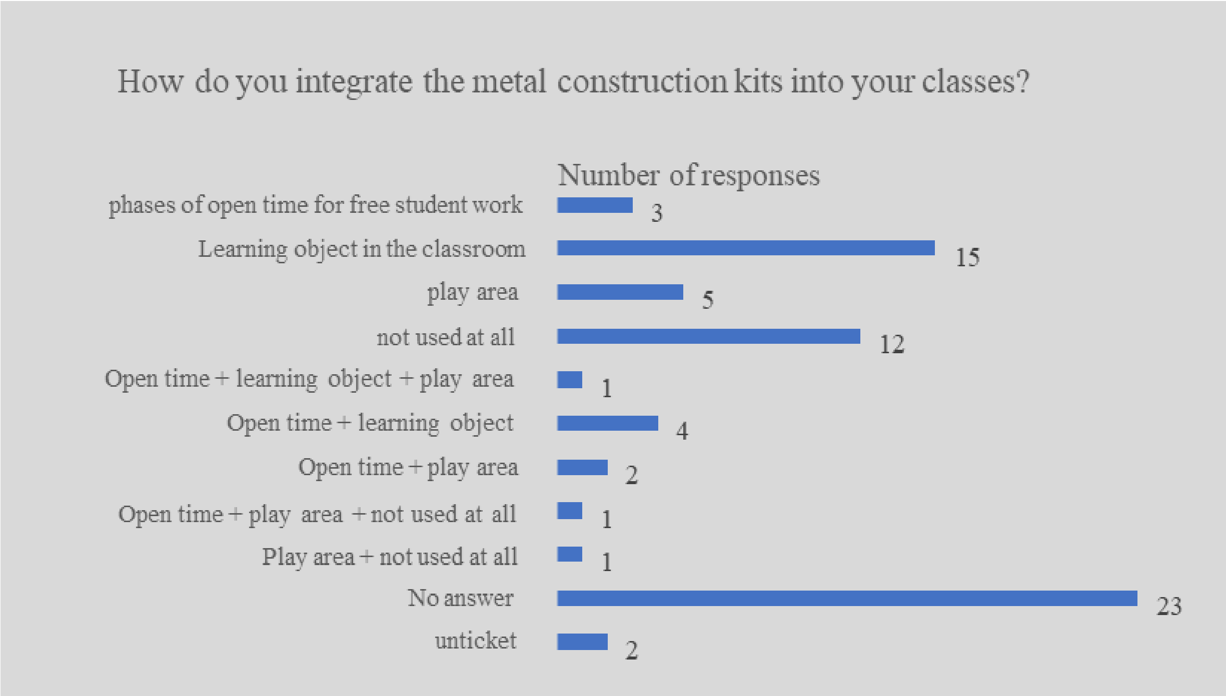

Figure 10. results of item number 21

Two participants use the kits in a combination of art and general science lessons. One person stated that they would use the metal construction kits as part of German, math, art and general science lessons. The subjects English, music, religion and sport were not selected individually or in any combination. However, three people left this question unanswered and 56.52% chose "no answer".

Regarding question number 21 (see Figure 10) 21.74% of the participating teachers use the technology kit exclusively as a learning object in the classroom. 17.39% responded they do not integrate the metal construction kits into their classroom at all. For 7.25%, the construction kits are only used in the area of free play of the classroom. Three teachers stated that they only integrate the technology kit in phases of open time for free student work. Four people chose the combination of open time for free student work and use as a learning object in the classroom. One teacher uses the box both in free work phases and as a learning object and otherwise stores it in the area of free play in the classroom.

Two teachers store the kits in their classroom that way, that the children can easy access them both during phases of open time for free student work and during play breaks. One person stated that although the kit is in the area of free play, it is not used. Another teacher expanded the combination of answers to include the option of use in free work phases. A third of respondents selected the "no answer" option to question 21 and two people left this question without responding.

In question 22, participants were able to provide further options for using the technology box, with seven out of 69 people providing the following answers (translated by authors):

- "During Corona, the construction kit was used for single children only."
- "Teaching with high gifted students"

- "The material is stored in drawers on a cupboard and is used as support material in addition to the working group."
- "Training of fine motor skills."
- „During additional childcare services at elementary schools"
- "Project days" (Cited by two people.)

Approximately 51% did not wish to provide any information on their satisfaction with the services offered as part of the support program. 26% stated that they were only partially satisfied. Nine teachers responded that they were satisfied with the offers. Three were not satisfied and four left the question open. 28 teachers selected that receiving more metal construction kits would help them to use them more frequently. The suggestion to publish specific teaching instructions received almost as many votes. Explanatory video clips were voted into third place as another useful offer with 20 votes. 17 considered pre-structured teaching units to be a helpful way of increasing the use of the construction kits. Eleven teachers thought that further in-person training would be helpful. Twelve participants considered online training to be useful. 16 people did not want to give a response and seven left the question without an answer.

Question 24 (outlined in Figure 11) was designed for collecting suggestions that would help teachers when using the construction kits. Nine people stated that there was a lack of resources in particular, as there was a demand for more material such as replacement boxes or additional extension sets, as well as for more time and staff or more teaching hours per week. The quality of the tools provided was also criticized. Others reflected that a study day and examples of best practice would help them. In addition, "it would be great if textbooks suggested specific tasks so that it will not be forgotten" (response from one participant, translated by authors).

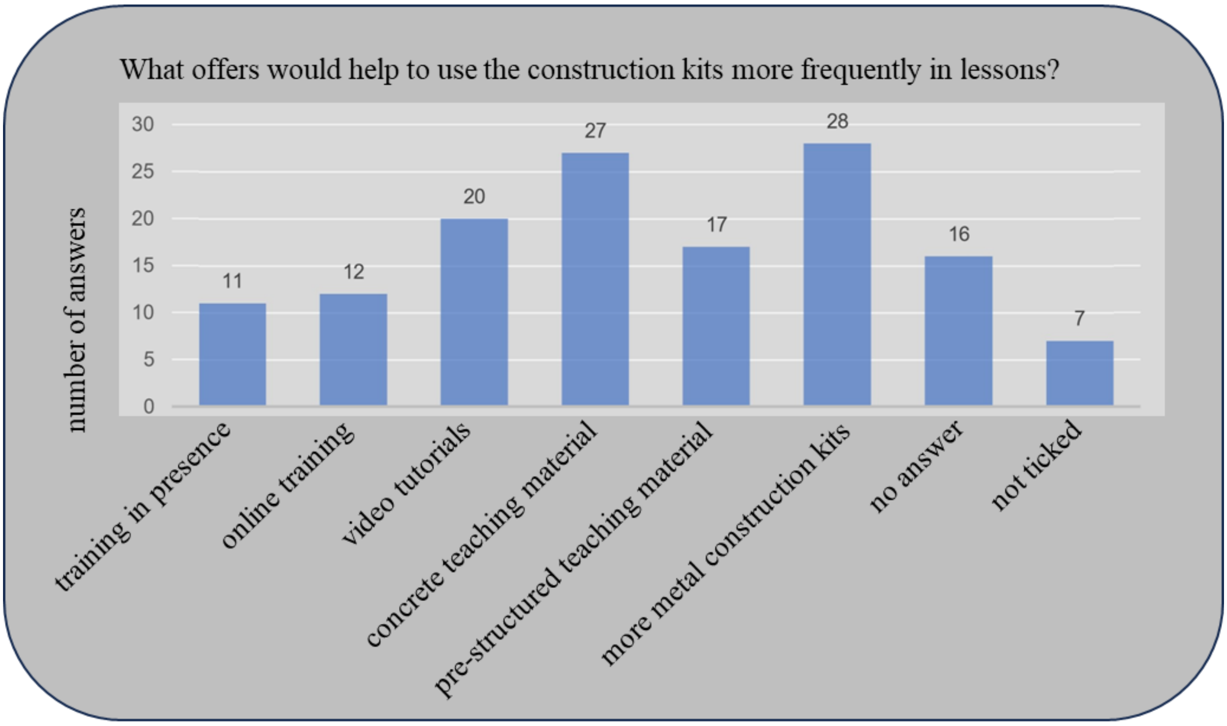

Figure 11. number of responses to item 24

26% of respondents to question number 26 made suggestions as to what they would have liked the Ministry of Education to do in the run-up to the start of the project in order to be able to work optimally with the kits. The following is an excerpt of some of the responses (translated by authors):

- "The problem is that the ministry regularly throws something new into the schools for implementation, but consistently ignores the fundamental problems such as teacher shortages, overworking school management etc."
- "A larger number of kits so that they can also be used in a classroom."
- "More staff, less actionism in clumsy acquisition and throwing it at the schools' feet."

In particular, there were calls for human resources and more free material. In addition, the suggestion was made several times that schools should be asked in advance whether they would like to take part in such a project in order to provide interested schools with a larger number of materials instead of just supplying them all with an insufficient quantity. Furthermore, an increased desire for more information and an introduction to the topic and advertising for such projects aroused. Isolated calls for schools to be involved in the selection of teaching materials were also proposed. In addition, one teacher commented that (translated by authors) "[one] could have done without the training that was provided [...] it was superfluous". Another person suggested that online training should be offered in the afternoons.

Almost half of the respondents were satisfied with the quality of the metal construction kits. As can be seen in Figure 12 only 3% answered they were not satisfaction, while 46% of ticked "no answer" and 2% left the question unanswered.

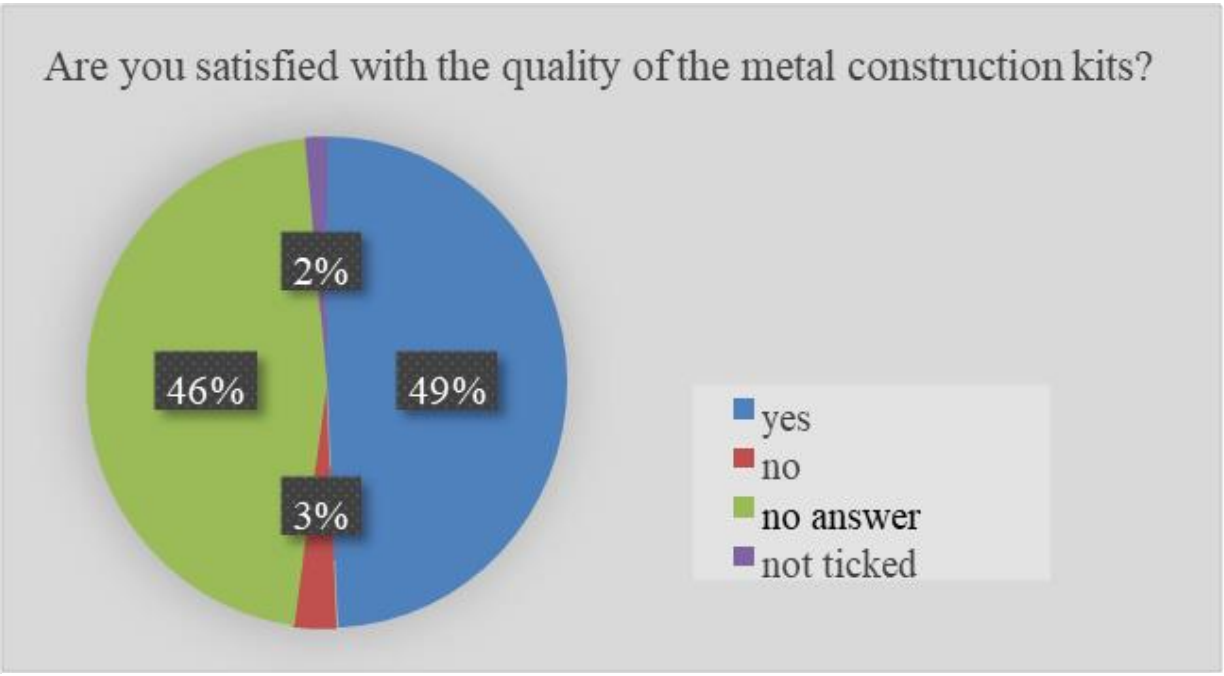

Figure 12. results of item 27

As illustrated in Figure 14 (item 28) 62% of all answers would accept more basic construction kits for their school if they had the opportunity. 7% would not accept any more metal construction kits. Around 28% gave no indication and just under 3% didn't answer.

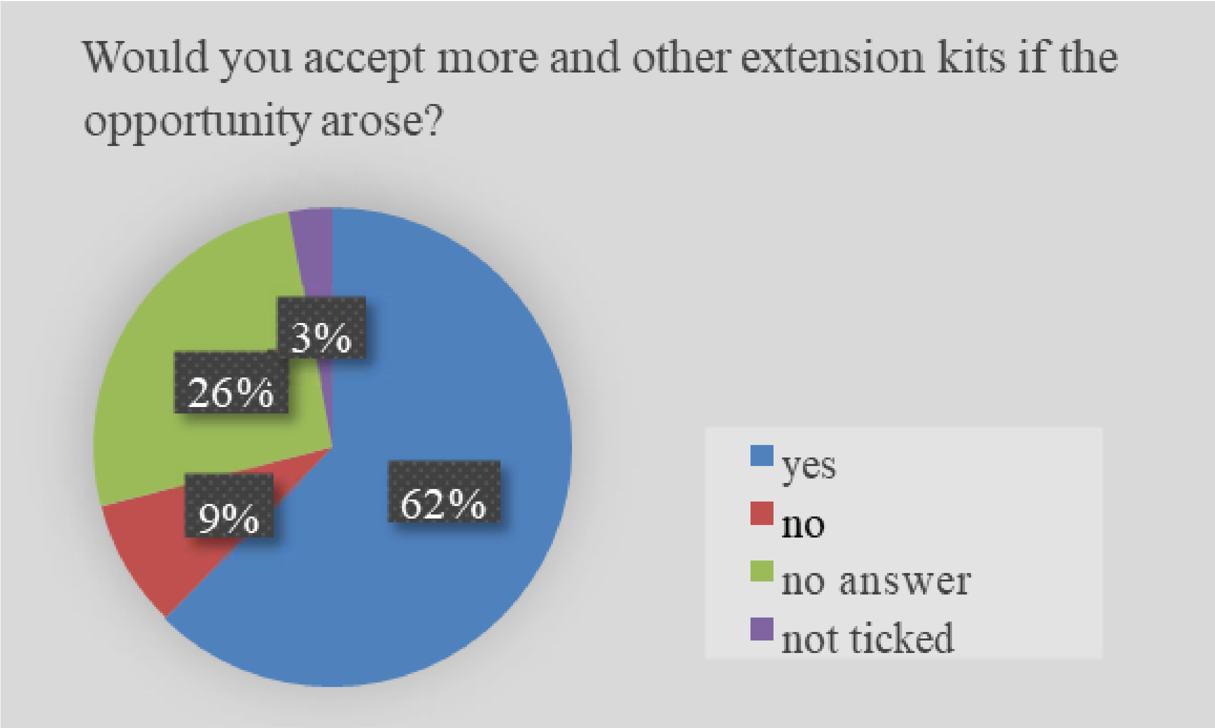

Figure 13. feedback to item 29

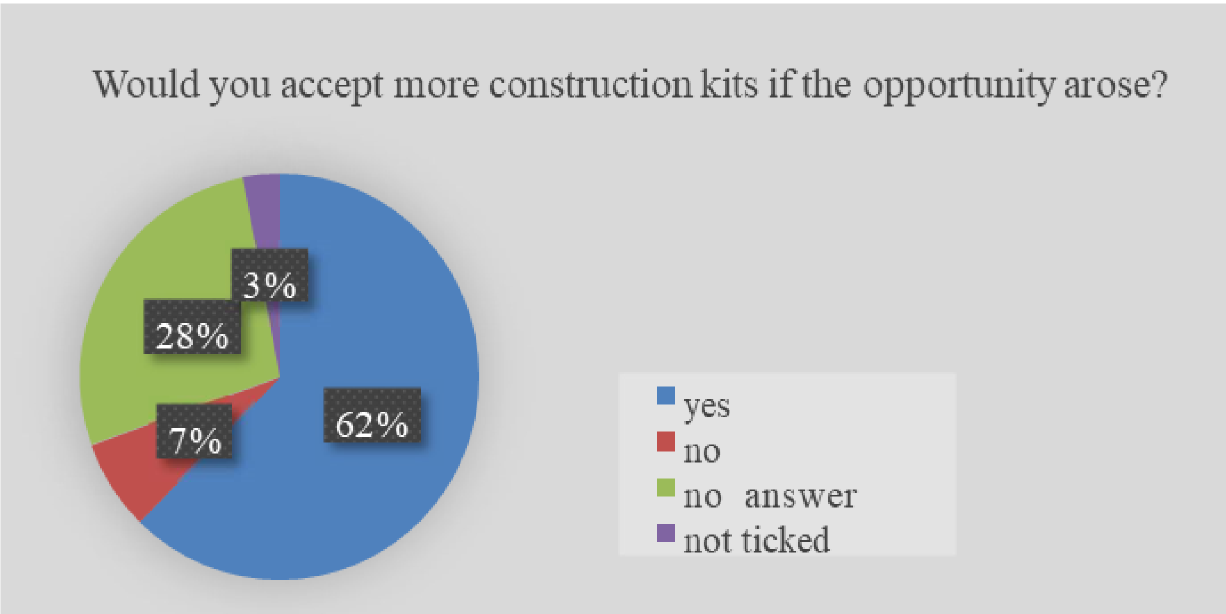

Figure 13. responses to question 28

Likewise, 62% of the teachers would accept additional extension sets of a different type for their school if they had the opportunity to do so (see Figure 14). However, 9% stated that they would decline this offer. 26% of respondents did not give a response and, as with question 28, 3% left this question without an answer.

Correlations between the questions

Only three of the 13 people who declared that they had taken part in the training were of the opinion that they were satisfied with the training offered. Seven of the 13 training participants were only partially satisfied, while one was dissatisfied. The others did not state how satisfied they were with the program. Only one of the participants of the training indicated that he did not use the metal construction box. For the other twelve, the boxes were either used in lessons or in the afternoon. 25 teachers who had not taken part in the training stated that their school would use the boxes either in the mornings in lessons or in the afternoons as part of a supervision program or in the form of an afternoon working group. Of these 25 people, eleven reported they were only partially satisfied with the technology box. Six of them were satisfied with the offers, despite not taking part in the training. Two of the 25 non-participants were dissatisfied. The remaining six non-training participants, who do use the technology box, did not state how satisfied they were.

Informal feedback

Based on the invitation email to participate in the survey that was sent to the schools, five schools expressed their interest in the survey. However, they did not want to take part in the survey as they either did not use the construction kits or had not received any. Of these, three schools reported back that they had not received any boxes but would be happy to take some if the opportunity arose. The other two schools did not use the delivered kits at all.

Discussion

The planned full survey revealed errors in the provided addresses and discrepancies in the available data sets from different sources. As a result, six emails could not be delivered, and it was not possible to ensure that all 921 elementary school received the invitation to the survey. Targeted follow-up campaigns were prevented by administrative requirements and the General Data Protection Regulation. In addition, it was not possible to determine whether several participants from the same school responded, which could lead to distortions in school-related questions. In question 4, for example, it can be assumed that the two people who stated that their schools each have a total of twelve metal construction kits are from the same school, as this answer stands out from the other responses. Otherwise, it can be assumed that at least one of the two participants made a typing error, as this field is a free text field.

Another assumption is that the participants originally wanted to give the answer "1-2", but the hyphen was not displayed in this field (only numbers permitted), resulting in the number 12. However, if there were no input errors, the assumption that the two people who each gave 12 complete basic construction sets are from the same school can be invalidated by the fact that the two teachers entered different numbers in the subsequent question on how many extensions sets the respective school has.

One reason for the large number of people who selected "I don't know" for questions 2 and 3 could be that, after 5 years of the project, they no longer remember how many boxes they received at the beginning. The statement that around 30% do not know the number of boxes at all and 38% stated that they have not yet worked with them suggests that they have not yet had any contact with the metal construction kits. Another assumption regarding the results for questions 4 and 5 is that in contrast to question number 1, where a picture of the basic set was included to avoid misunderstandings, a picture of the extension sets was not provided to understand the exact difference between the basic kit and the extension set.

It can be assumed that the majority of participants did not know which construction set belonged to which question and therefore already included the extension sets in question 4. For example, one person stated that their school currently had 26 complete basic construction sets, but no extension sets. With this information, it can be assumed, among other things, that the assignment of the boxes with the terms “basic” and “extension” was not entirely clear.

For questions 7 and 13, it is noticeable that 35% of respondents did not answer in each case. One reason for this could be that the previous question in each case breaks down an if-then structure and participants are therefore asked with their answer in question 6 or 12 to continue with another question and thus skip questions 7 and 13. In the case of question 7, all respondents did it and followed the intended flow chart. In contrast, seven participants gave a different answer to question 13 and did not continue with question 15 as requested. The reason for this behaviour could be that the participants did not read the description carefully and thought that they also had to answer the next question.

The large proportion of those who did not wish to provide any information, such as in question 20, could be explained by the fact that towards the end of the survey there was no more time or motivation to read the question-and-answer options carefully and the participants therefore ticked a neutral answer option.

Conclusions and Implications

As the results have shown, the metal construction kits are hardly used or not used at all. Almost 30% of participants were not even aware of the kits, while one in five survey participants stated that their school had not received a metal construction kit at the start of the project. This situation means that one of the most frequently cited reasons why schools do not use the metal construction kits in their lessons is that they have too little or no learning material.

On the other hand, the study shows that the majority of teachers consider the opportunities to use metal construction kits in lessons to be useful. In addition, it was expressed several times to accept more boxes in order to increase the number of metal construction kits. It can be assumed that only a limited number of kits were given to the schools in order to initiate additional purchases by schools, while the interviewees almost universally stated that the budget provided by the school authorities was insufficient for the purchase of additional kits. With regard to the overall costs of the project, the question therefore arises as to whether the funds spent by the Ministry represented a sensible investment.

One of the main reasons why teachers did not take part in the training is that they were unable to find the time or capacity to do so due to staff shortages at school. It can be assumed that the training locations are also linked to this, as the 12 training locations, in contrast to the school locations, tended to be on the outer edge of the federal state. Even if the training provider considers the location to be balanced (Holder, 2023), teachers from the centre of the state in particular complained about the long journey.

Another problem highlighted by the results of the study is internal school communication. The fact that 30% of participants were unaware of a statewide STEM support project and that teachers repeatedly reported in the course of the survey that they had not received any information about the kits gave cause for concern. One reason for this could be that there is not enough advertising for such projects or that they are not communicated to the teachers. It is important to question whether all emails that primarily concern teachers should be sent exclusively to the school management or whether a different system could be established to inform teachers in the best possible way.

Furthermore, future studies should consider examining the school's internal communications in order to identify the source of the information block between the ministry and the teacher and to develop possible suggestions for improvement.

Recommendations and Future Research

In conclusion, it can be said that schools are generally interested in support programs and also consider the use of the metal construction kits to be useful but would like to be asked in advance whether they would like to participate in such a project. Teachers hope that this will enable them to receive a larger number of materials from the Ministry of Education, as funds would then only have to be spent on interested schools.

In addition, the passing on of information appears to be a fundamental problem. In future studies, it would be interesting to find out whether the school management received the information but did not pass it on to the teachers or whether the school management did not receive any information about the project or the training dates for various other reasons. In order to circumvent the information, stop by the school management, it should be considered whether in future, with such cost-intensive projects as this one, the information should be sent directly to the teachers in order to advertise the use and further training opportunities.

In addition, the choice of training dates and locations should be reconsidered, as there were no training opportunities in many districts, which meant long journeys and a great deal of time. Online training courses or asynchronous explanatory videos should therefore also be considered for future projects in order to reach a larger number of people on the one hand and to act in a more economically and ecologically conscious manner on the other. Teachers would also like specific teaching materials to support and guide the use of the boxes in the classroom.

Another way to increase publicity for a STEM funding project of this size is to visit as many schools as possible in different districts at the start of the project and organize a morning together with the children using the new material to whet their appetite for more. The aim of such a day would be to arouse the children's interest in continuing to work with the boxes and for the teachers to experience a best-practice example in a direct teaching situation, thus reducing the inhibition threshold to try something new.

Another aspect that could increase the use is the inclusion of the metal construction kits in the existing loan range of the training courses offered by the "Pädagogisches Landesinstitut" (transl.: pedagogical institute of the state). One argument in favour of including the kits in the range would be that schools could borrow exactly the number of boxes they need, as smaller classes need fewer boxes than larger ones in order to be able to work optimally. This could also save costs and resources by not purchasing boxes that are not used.

Another idea that could increase the use of the kits in schools would be to launch a follow-up campaign after five years of the project launch, giving schools the opportunity to register for a new collective order at favourable conditions in order to obtain the quantity of boxes needed for optimal use.

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29.2

Aligning Hangarau Perspectives: Exploring Curriculum Coherence in Māori-medium Technology Education

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Abstract
This paper is the fourth in a series exploring the issue of curriculum coherence in the development and implementation of the three iterations of Māori-medium Technology curriculum from the 1990s to the present. For Indigenous schools, curriculum coherence is not just a structural design issue but also involves the place of their Indigenous knowledge systems, cultural values, and educational philosophies. This paper investigates the challenges and opportunities to develop a Māori-medium Technology curriculum based on an Indigenous philosophy of Hangarau. Data is drawn from Ministry of Education archival files and interviews with developers of curriculum and curriculum support materials. It utilises document analysis and interviews with curriculum experts (referred to as mātanga in this paper). This study reviews literature around curriculum design in Aotearoa New Zealand, particularly meta-analyses, and reviews, in the context of curriculum coherence. Curriculum coherence affects student learning across various levels: national, subject, school/classroom, and systems. It examines how curriculum coherence relates to the challenge of alignment between curriculum and curriculum support materials for teachers implementing the Hangarau curriculum, and the challenges in teaching of interpreting the learning outcomes. The paper concludes with recommendations to align national curriculum design, content, and implementation for more effective support of developers, teachers, students, and communities in Indigenous language learning contexts, enhancing student learning outcomes.

Keywords
Hangarau, Māori-medium Technology, curriculum coherence, Indigenous Technology, Technology curriculum

Introduction
In Aotearoa New Zealand (NZ) there are two nationally mandated curriculum frameworks, one for English language educational contexts, referred to as English-medium, and one for Māori language educational contexts, referred to as Māori-medium. Curriculum design for schooling in Aotearoa has evolved in response to a complex interplay of societal, technological, and educational influences, reflecting changing perspectives on teaching and learning and the evolving needs of students and communities. Similarly, curriculum design, both for Māori the Indigenous people of Aotearoa NZ and for other Indigenous groups globally has changed significantly over the decades, influenced by various factors including educational philosophies such as assimilation, globalisation, and changing societal needs. Much has been written about the impact of Eurocentric curriculum on Māori student experiences in English-medium education over the past 150 years (see Benton, 1979; May & Hill, 2018; McKenzie & Toia, 2022; Simon, 1992; Simon & Smith, 2001; Skerrett, 2019; Stewart & Tocker, 2021). However, there is a paucity of literature examining the impact of Māori curriculum design on Māori-medium education in Aotearoa NZ. This is in part because Māori-medium education and curriculum development are relatively new fields (emerging in the 1980s) and there are few researchers

working in these areas. Despite self-determination being one of the key ideologies underpinning Māori-medium education, because of its marginalised nature, it continues to be significantly impacted on by the ideologies underpinning the majority Eurocentric education system. This includes the needs of students in Māori-medium schooling still being determined by the needs of English-medium schooling (Toia, 2021; Trinick, 2015).

This paper examines how the Eurocentric ideologies of the state who control curriculum development in Aotearoa NZ has impacted on the coherence of the various iterations of Māori-medium curriculum development since the 1990s, with a particular focus on the Marautanga Hangarau [Māori-medium Technology curriculum]. Curriculum coherence refers to the logical and sequential connection between different elements of a curriculum, ensuring that each component aligns with the overall educational goals and objectives. It emphasizes a cohesive structure that promotes meaningful learning experiences for students (Roach et al., 2008; Wenzel, 2016). The study's methodology is examined, followed by a discussion of key findings arising from interviews with curriculum experts (referred to as mātanga in this paper) and Ministry of Education policy documentation. In consideration of the findings, a series of recommendations is made to better support the coherence of current and future Hangarau curriculum development and implementation.

The Changing Educational Landscape of Curriculum Design for Māori

Prior to colonisation, Māori education was primarily oral and experiential, centred on community, and lifelong learning (Hemara, 2000; Riini & Riini, 1993; Trinick, 2015). Elders played a crucial role in transmitting knowledge through practices such as taupuhi [observing children's dispositions to inform curriculum design], storytelling, and guiding children's participation in community activities (Hemara, 2000; Maxwell & Ngata, 2011; Maxwell et al., 2022). Learning was holistic, communal, and interconnected, without the compartmentalisation of knowledge into subject areas as is the case now.

With the arrival of Europeans in the 1800s came the introduction of novel technologies and writing systems, recognised by Māori for their economic potential (Petrie, 2006; Simon, 1992). Māori leaders sought literacy skills to navigate written agreements and treaties shaping interactions with Europeans. In these early interactions, there was the potential for an equal educational partnership in Aotearoa NZ (Jones & Jenkins, 2011; Lemon & Durham, 2017). However, two contrasting education goals were held by European and Māori during the early colonisation period (Hetaraka, 2022; Trinick, 2015). The Pākehā [European] dominated settler government aimed to assimilate Māori into European culture (Simon, 1992), while Māori welcomed Western education for its potential to enhance their way of life (Simon, 1992; Spolsky, 2005). Over time, power dynamics shifted as Europeans gained political control. Māori leaders sought to assert sovereignty and protect their lands, leading to the Declaration of Independence (Te Rua Mahara o Te Kāwanatanga: Archives New Zealand, n.d.) and Te Tiriti o Waitangi [The Māori-language version of The Treaty of Waitangi, popularly referred to as Te Tiriti] (Ministry for Culture and Heritage, 2023). Considered by many to be Aotearoa NZ's founding document which established a formal foundation for the relationship between the indigenous Māori people of New Zealand and the British Crown. It outlines principles of partnership, participation, and protection of Māori rights and interests (O'Malley & Harris, 2019; Wright, 2019), Te Tiriti reflects intricate dynamics between Māori and European interests, shaped by the context of the time and the evolving relationships between the

Indigenous population and the British Crown. These documents continue to be significant in Aotearoa NZ's contemporary education issues including in the development of curricula for Māori-medium schooling (McKenzie & Toia, 2022; Trinick, 2015).

Despite these early treaties in the 1800s recognising Indigenous Māori rights, by the turn of the 1900s, the state education system extended bans on the use of te reo Māori from classrooms to playgrounds (Hetaraka, 2022; O'Regan, 2018). Legislation like the Education Ordinance of 1847 and the 1867 Native Schools Act led to the complete exclusion of te reo Māori from many schools and the punishment of children for speaking it up to the 1960s (Simon & Smith, 2001; Skerrett, 2019). During this time, some formal resistance from Māori began to emerge to English-language hegemony in education, although in a limited form. However, after a century of absence, Māori language and culture were re-reintroduced as subjects into a few secondary schools in 1962 (Trinick, 2015).

Urban migration of Māori post-World War II completely altered the country's demographics (May & Hill, 2018), further contributing to language and cultural loss as Māori moved from communities where Māori language was commonly used to urban areas where te reo Māori [Māori language] use was actively discouraged (McKenzie & Toia, 2022). The change in the status of te reo Māori, from an initially high-status language of early colonial communication to a low-status language in Aotearoa NZ, was a major factor in the language shift to English in Māori communities. By the 1970s te reo Māori was considered an endangered language (Benton, 1979; Spolsky, 2005). It was against this background of rapid and significant language loss that Māori communities initiated bilingual education in Aotearoa NZ in the 1980s (May & Hill, 2018). These early bilingual schools were required to follow the English-medium syllabus for schools (Trinick, 2015)—there was no formal Māori-medium curriculum, and limited resource materials to support learning and teaching in te reo Māori.

Contested nature of Māori-medium Curriculum development 1990s-2024

After extensive lobbying by various Māori-medium education stakeholder groups for over 10 years, in the 1990s, the Government eventually agreed to develop Māori-medium curricula in the Māori language (McMurchy-Pilkington et al., 2013). While this recognition was agreeable on one level, as this was the first time in the long history of schooling that Māori educationalists (referred to in this paper as mātanga) were given any authority to develop State curricula, there was a requirement that the Māori-medium version be based on the parallel English-medium version (Lemon, 2019; Lemon et al., 2020; Trinick & May, 2013). This included the development of the Māori-medium Technology [Hangarau] version (Lemon, 2019; Lemon et al., 2020). Several of the group eventually contracted to develop the Māori-medium version had also been involved in developing the Technology curriculum (Ministry of Education, 1995). According to one of the informants for this study [Curriculum expert or Mātanga 4] there was a desire to design the inaugural Hangarau 'curriculum' based on Māori philosophies, but they were thwarted by contractual requirements including that the Māori-medium version be developed explicitly using the design of its English-medium counterpart (Lemon, 2019; Lemon et al., 2020). This lack of alignment between the philosophy of the Hangarau curriculum and Māori-medium schooling created several issues which persist to this day including the perpetuation of a Eurocentric bias in technology education and the reinforcement of the dominance of Western ways of knowing, further marginalising Indigenous voices and contributions (Lemon, 2019; Lemon et al., 2020).

In the subsequent round of development of Māori-medium curricula in 2007 and 2008, while there was a requirement that the basic structure of the 1996 curricula be maintained, there had been significant change in the Ministry of Education. As such, the government were much more accommodating of Māori attempts to indigenise Hangarau (Lemon, 2019; Mātanga 1; McMurchy-Pilkington et al., 2013), some of which were arguably represented through the increased use of metaphor in Te Marautanga o Aotearoa (TMoA; The national curriculum framework for Māori-medium education) (Mātanga 1; Mātanga 3). Māori capacity had increased with mātanga holding key positions in the Ministry, coupled with an increased capacity to write curricula, and there was a more robust round of community consultation during the second round of development (Ministry of Education, 1999-2008). Although there was still a paucity of research, work focused on Te Reo Matatini [Māori-medium literacy] Pāngarau [Māori-medium mathematics] and more generally on related concepts, was emerging. There was also an opportunity for the learning area teams to collaborate, which had not been allowed in the inaugural design of the 1990s (Mātanga 3; Mātanga 5). Time was invested in the TMoA principles re-development (the frontpiece, articulating the underlying beliefs, values, and theories guiding the development and implementation of TMoA) and in the standardisation of the lexicon across the curriculum areas (Lemon, 2019; Trinick, 2015).

The Hangarau Curriculum Document

The evolution of the Hangarau curriculum reflects a journey shaped by shifting educational paradigms and cultural aspirations. Initially, the curriculum design in the 1990s indicated a parallel structure to the English-medium Technology curriculum, depicted using an oval shape split into two strands: technological literacy and mātauranga Māori (societal knowledge and ethics). A whāriki [or woven mat] situated the seven kaupeka [transversal elements or contexts for learning, see 1 and 2 in Figure 1] for Hangarau practice in relationship to the two strands (see 3 and 4 in Figure 1). Subsequent iterations, particularly the establishment of Te Marautanga o Aotearoa [TMoA] in 2008, aimed to integrate Māori perspectives and values, involving collaborative stakeholder engagements, emphasising both linguistic consistency and cultural authenticity.

Hangarau became a core learning area (a compulsory subject to be taught in all classes from 2011) and was depicted using a moki [a species of trumpeter fish] wrapped in a whāriki [a woven flat mat]. This iteration continued to emphasise ethical practice, environmental stewardship, and the interdependence of Hangarau skills with Hangarau knowledge, with a stronger focus on the importance of local knowledge.

The seven kaupeka had been revised and there were now five named elements or contexts for learning, now referred to as aho. In 2017 one of the contexts was removed (ostensibly to be ‘embedded’ in practice throughout the rest of the Hangarau contexts) to accommodate the introduction of Hangarau Matihiko [Māori-medium Digital Technologies]. Through these transformations, the Hangarau curriculum continues to evolve, embodying a dynamic interplay between tradition and innovation, and serving as a testament to the resilience and adaptability of Māori-medium education (See Lemon 2019, Lemon et al, 2020; and 2023 for more in-depth explorations of the Hangarau curriculum documents).

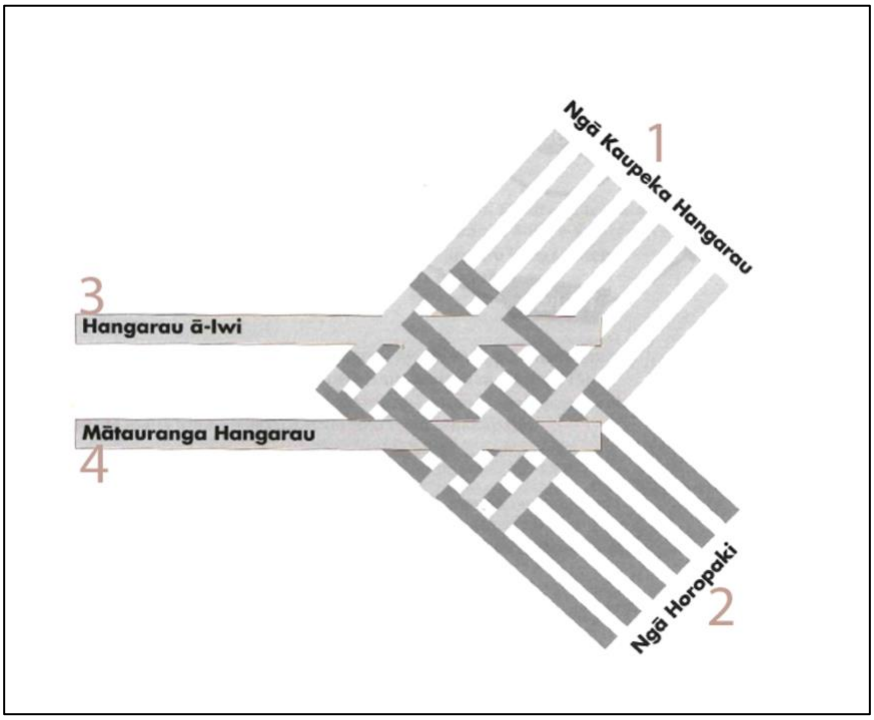

Figure 1. The inaugural structure of Hangarau (Ministry of Education, 1999, p. 20). Reproduced with permission from the Ministry of Education.

The philosophy of Hangarau seeks a balance between the preservation and reinterpretation of mātauranga Māori [Māori knowledge], integrating ethical decision-making, critical thinking, and sustainability principles into technological literacy education (made explicit through interviews with mātanga). It will be discussed further in the "discussion of data" section.

Indigenising the Curricula: Where are we Now and Where to Next?

Throughout the 2000s, more favourable education policies emerged, for example, the Ministry of Education commissioned a position paper on Aromatawai [Māori-medium assessment] (Pōhatu et al., 2014) that supported the illuminating of Māori knowledge in Māori-medium schooling. This assessment position paper advocated for the equal recognition or mana ōrite of Māori knowledge with Western in the National Certificate of Educational Achievement [NCEA]. NCEA is the senior secondary school assessment and credentialling framework into higher education in Aotearoa NZ. Mana ōrite acknowledges that Māori-medium and English-medium, have similarities and differences reflecting their respective communities' philosophies and world views (Pōhatu et al., 2014). The development of a Māori-medium assessment position paper supported a greater alignment of the Hangarau curriculum with Māori goals and aspirations for schooling (discussed in the methodology section). Mātanga Māori (Māori curriculum designers) conducted systematic literature reviews to inform the re-development of Te Marautanga o Aotearoa [TMoA] from 2023-2025 (Allen et al., 2022; Trinick et al., 2022) including discussions on unique Māori teaching and learning pedagogies. This included the concept of student-centred learning which was a common pedagogy adopted by Māori-medium schooling (Allen et al., 2022). However, the recommendation to the Ministry of Education was that the notion of child centred learning is different in Māori-medium in comparison to English-medium. The major difference is that the student in Māori-medium schooling is not just considered as an individual, but as a part of a community. The Māori student-centred learning collective consisted of relationships with teachers, whānau [family], hapū [extended family] and others, as well as the dynamics of these ongoing relationships and connections to place-based knowledge. Additional research was commissioned by the Ministry of Education on the various competing theories on the organisation and sequencing of curricula including a design which best suited the needs of Māori-medium schooling (Trinick et al., 2022).

Collectively, this policy change and research (Allen et al., 2022; Pōhatu et al., 2014; Trinick et al., 2022) shifted the narrative informing the design of future curriculum to be better aligned to the philosophies of Māori-medium education. For example, the current 2023-25 re-development argues strongly for greater curriculum alignment philosophically between the early childhood, primary and secondary Māori-medium sectors. While there were still design constraints, there was a shift from the previous adherence to English-medium curriculum design as was the case in the 1990s to one that positioned Māori-medium curriculum design closer to realising the aspirations and goals of the Māori-medium education community (Toia, 2021). However, the Māori-medium education sector is very diverse politically. This adds to the challenges of developing a single state curriculum for all schooling models (Trinick & Heaton, 2020).

One of the other challenges is that about 70% of students in Māori-medium schooling transition out to English-medium schools after the primary school level (age 13) and do not attend wharekura [Māori-medium secondary schools, the last five years of formal schooling as teenagers]. On July 1, 2023, 5,238 Māori students were enrolled as secondary students in Māori-medium contexts (Education Counts, 2023). The issue of small scale is further exacerbated by only a few secondary students studying Hangarau at the upper levels of the secondary (Nippert, 2021). Of the few students choosing to take Hangarau as a subject, the majority are enrolling to complete their required assessments through the English-medium New Zealand Curriculum (Ministry of Education, 2017b) Technology Assessment Standards (Nippert, 2021) because there were not enough teachers with the expertise to teach at the upper levels, nor appropriate resources available. What this shows is there remains structural misalignment at the classroom level, thus leading to a great lack of coherence.

Greater governmental support is needed to minimise these challenges, grow the sector, and consider the future trajectory of the Māori-medium sector in the current 2023-25 curriculum refresh. Mātanga Māori interviewed for this study have advocated for systemic changes at all levels. They are not convinced that the ideal philosophical alignment has occurred yet, and work remains to develop a more authentic Indigenous curriculum (Ministry of Education, 2021; Te Pae Roa, 2022a, 2022b). Of current concern however, with a change to a more conservative government is whether developers will retain the latitude to develop a curriculum more reflective of Māori-medium schooling community aspirations and goals.

Methodology: Curriculum Alignment and Coherence

This section provides an overview of the research methodology and the data collection method for this study. This paper builds on an earlier study that focused on the first two iterations of the Hangarau curriculum document between 1999 and 2008 (Lemon, 2019). This paper concentrates on the first three iterations of the Hangarau curriculum and the curriculum support materials (otherwise known as second tier materials), drawing in the current development cycle where appropriate.

Curriculum coherence, as a methodology, entails a systematic approach to designing, organising, and implementing a curriculum to ensure unity, alignment, and logical progression of learning experiences (Wenzel, 2016). Fullan's (2007) inquiry into curriculum implementation underscores the importance of coherence for sustaining effective educational practices over time. It highlights how a well-coordinated curriculum can enhance the sustainability of teaching and learning initiatives by aligning various components such as learning objectives, instructional materials, and assessments (Roach et al., 2008).

However, despite its benefits, the concept of curriculum coherence has weaknesses. For instance, rigid adherence to predetermined curriculum structures could stifle creativity and flexibility in responding to diverse student needs and changing educational contexts. Additionally, achieving coherence across all levels of the education system may pose challenges due to differences in priorities, resources, and stakeholder interests (Sullanmaa et al., 2021). Thus, while curriculum coherence is valuable for promoting effective teaching and learning, careful consideration of its limitations and adaptability is essential for its successful implementation. Successful implementation of curriculum coherence plays a large role in ensuring consistent and robust curriculum delivery across the school, thereby improving the quality of students' school experience.

Data Collection Methods

There were two sources of data for this paper. The first was secondary data collection which involved a series of information requests to the Ministry of Education (the agency primarily responsible for curriculum development and the authoring of second tier professional development and teaching support materials in New Zealand) under the Official Information Act 1982. The dataset included: Contracts; schedules of payment; budgets; milestone reports; letters to schools; press releases; email trails; meeting minutes; surveys; production schedules; working drafts of both the curriculum statements, and potential structures, as well as drafts at various stages in the production of a range of resources – including video, DVD, written and online materials (Ministry of Education, 1999-2000a; 1999-2000b; 1999-2003; 1999-2008; 2003-2012; 2007-2009; 2008-2010; 2010-2011). The milestone reports and working drafts were particularly helpful in communicating key thinking about curriculum development and curriculum support materials at that time.

The second data source was interviews with experts, or mātanga who were involved in the development and/or implementation of the Hangarau curriculum during its three developments, in the 1990s, 2006-8, 2015-2017, Mātanga 1-3 [coded as M1-3] being involved in the current curriculum refresh which started in Aotearoa NZ in 2021. In the Indigenous Māori context, mātanga are considered experts in a particular field. In this paper, it refers to experts with a teaching background, who have worked on the Hangarau curriculum, and have worked on the development, implementation, trialling, and distribution of second tier materials to schools (see Lemon, 2023 for a discussion focusing on Professional Learning Development). Due to the incredibly small pool of mātanga in the Māori-medium education sector, anonymity and confidentiality could not be assured. All mātanga had the choice – first, to participate in the research; and second, whether they wanted to use a pseudonym or their real name. All left the choice up to me, so I have used pseudonyms, erring on the side of caution. Interviews were conducted with five mātanga. Their views of the development of the Hangarau curriculum

(Ministry of Education, 1999, 2008, 2017a) with respect to the nature of curriculum and its second-tier materials are discussed after the mātanga are introduced below.

Mātanga tuatahi [M1] managed the re-design of Te Marautanga o Aotearoa [TMoA] in 2004, leading the design of curriculum support materials for 18 years. Mātanga tuarua [M2] led the inaugural Hangarau document development in the 1990s. Mātanga tuatoru [M3] was in the advisory group for science, before leading Pāngarau [Māori-medium mathematics] development in the 1990s. M3 also worked on the standardisation of the lexicon across TMoA. Mātanga tuawhā [M4], initially contributed to Technology curriculum development before joining the inaugural writing team for Hangarau and then working as a Facilitator. Mātanga tuarima [M5] was a PLD facilitator, regional coordinator, and designer of second tier curriculum support materials. M5's focus has been on providing classroom teachers with resources for exploring and engaging with the Hangarau curriculum. M5 was a member of the Hangarau Matihiko [Māori-medium Digital Technologies] reference group (Ministry of Education, 2017a).

Coding and Data Analysis

The dataset, the documents and the interviews, were coded and analysed using "In Vivo Coding" (Saldaña, 2022, pp. 137-143) for the first-cycle of coding, and then "Focused Coding" (pp. 307-307) was applied for the second-cycle of coding. Analysis was conducted through an adapted approach to thematic analysis (Braun & Clark, 2006; Guest et al., 2012; Thomas, 2006). Initial In Vivo codes were generated for the complete dataset, then a second cycle of Focused Coding was conducted (See Lemon et al., 2023 for more detail on coding and analysis). An outline of the synthesis in relation to the Hangarau curriculum and its support materials is discussed below. Table 1 shares an outline of the key second tier Hangarau curriculum materials that were detailed in the documents and then each of the following notions identified as being a significant notion in relation to first and second tier materials from the dataset is outlined briefly. The findings have been summarised very briefly in the next section.

Table 1. Second-tier Hangarau Curriculum materials focused on in the Ministry of Education documents sourced under the Official Information Act 1982

Date/Year	Authors	Description	Request #
1999	Copeland Wilson and Associates	Hangarau video	1100564
1999	Waiti Associates Ltd	A teachers' handbook aimed specifically at supporting programme development at secondary school (I have been unable to source a final copy of this resource).	1139624 and 1242781
2001-2003	Te Tihi	Tauaromahi [exemplars] project	1100564
2007-2009	Huia	A Hangarau Koiora [Māori-medium Biotechnology] text focused on supporting teachers of students working at level 6.	1118980
2008-2010	Tihi Ltd and Palisade Film Productions	From tender round for Māori-medium materials to final milestone (including draft content), focusing on the DVD set, with accompanying student books, aimed at teachers of year 9 and 10 students (junior secondary)	1207583

2010-2011	Kōtaretū	Organising a re-print of two key resources – 1,000 copies of Hei Tautoko i te Hangarau; and 300 copies of the DVDs, each of the student books and of the teacher's book for Tūhurutia te Ao Hangarau.	1241126

Discussion of Data

While the main aim of the paper was to examine the alignment and thus coherence of the Hangarau curriculum at all levels, a secondary aim was to examine an Indigenous philosophy of Hangarau, how this influenced the content, design, and structure of the marau [curriculum], acknowledging, and reflecting Indigenous knowledge, and pedagogy. It was also important to consider the implications these concepts have on classroom implementation and the enactment of the marau Hangarau. One of the key factors impacting on the design was linguistic. That is because language plays a crucial role in curriculum design and writing as it determines how content is communicated, understood, and internalised by learners. The choice of language can influence accessibility, inclusivity, and cultural relevance within the curriculum. It shapes the clarity of instructions, the presentation of concepts, and the development of learning materials, impacting students' engagement and comprehension. King Charlemagne is quoted as saying, 'To have another language is to possess another soul' (n.d.).

Researchers in the field of sociolinguistics tend to agree that, while more research is needed, to some degree, your personality and your behaviour, down to the decisions you make are influenced by the language you are speaking (Bialystok, 2017; Chen, 2013; Cook, 2008; Harrison, 2010; Kramsch, 2014; Royal, 2019; Sapir, 2002; Stewart, 2020; Whorf, 1956). One of the central themes that emerged from the interviews was the important role of language serving as a lens through which individuals and groups perceive and interpret their surroundings. When a language is lost or marginalised, vital cultural and conceptual frameworks embedded within that language may also be lost (Royal, 2019; Trinick, 2015). Revitalising a language allows its speakers to reconnect with unique ways of understanding and interpreting the world, potentially leading to shifts in perception and worldview. Language is closely tied to individual and collective identities (Bialystok, 2017; Harrison, 2010; Stewart, 2020). Speaking a particular language is often intertwined with one's sense of belonging to a cultural or ethnic group (Boroditsky, 2001; Stewart, 2020). When a language is endangered or suppressed, it can lead to feelings of cultural disconnection and loss of identity (Kramsch, 2014; Royal, 2019). Revitalising a language can strengthen cultural pride and identity among its speakers, fostering a sense of community and belonging. Language not only reflects cultural norms and values but also shapes social interactions and behaviour. Revitalising a language can lead to changes in social dynamics, communication patterns, and interpersonal relationships within a community. It may also promote intergenerational transmission of cultural knowledge and traditions, influencing social cohesion and collective action (Stewart, 2020). Thus, for Māori-medium education the revitalisation of te reo Māori [Māori language] is a critical goal of Māori-medium education. This critical goal seeps through out the sector including influencing how the matanga interviewed for this paper viewed Hangarau curriculum development.

> *We fought as Māori for the revitalisation of the reo, for the revitalisation of our taonga [treasures], of our practices and hangarau was going to be, like every other thing, a vehicle to get that back. (Mātanga 4) "Mātauranga Māori [Māori knowledgebase], te reo Māori was everything" (Mātanga 1).*

Another theme was the need to increase the presence of mātauranga Māori in the curriculum, initially through the preservation of knowledge, to an attempt now at grounding the document in mātauranga Māori and supporting schools in the development of localised curriculum: "The bits and pieces of narrative that people bring to a practice, and no-one was incorrect" (Mātanga 4). "Te whakamana i ngā mātauranga o ngā tūpuna kia ora ai" (Mātanga 5; Normalising/validating/celebrating the knowledge of the ancestors to thrive). All mātanga spoke of the importance of researching, reclaiming and reframing mātauranga Māori, which in the 1990s, was aiming at being a decolonising curriculum:

> *This was the first official curriculum that said, Māori mā [addressing Māori people as a collective]. Here it is. Make it your own. Do what your old people used to do and make it your own so that our kids in the next generations always know where they came from – what the whakapapa [origins and development] of this taonga was. … The heart of the matter is still hangarau and our kids' ability to take what our tupuna [ancestors] did and move that on to their own space in the digital future. (Mātanga 5)*

There was also emphasis placed on the need for hybridity and evolution of the knowledgebase (Allen, 2023). The concept of students walking in two worlds – one rooted in mātauranga Māori and the other in a Western worldview – may no longer be referring to two separate and disparate worlds. The mātanga acknowledge the importance of relevance and adaptability, with a need now to reflect on what aspects of the knowledgebase are most important for our next generations. There is a highlighted need for a clear distinction between national guidelines and curriculum frameworks and locally developed curricula, supported adequately by the government.

> *I'd like to see the emphasis shift more to supporting schools to develop their localised curriculum or regional curriculum or an iwi [tribal] curriculum and the Ministry resources this because the schools can't do it by themselves (Mātanga 3) "…how they get involved and what their local knowledge means to any solutions that are found" (Mātanga 2).*

Another major issue that disrupted alignment was the lack of support resources, either in text and electronic form and critically in adequate teacher supply. This is made more significant because of the correlating lack of ongoing systematic Professional Learning and Development [PLD] as suggested by Lemon (2023). Additionally, the creation of robust materials is proposed to assist kaiako [educators] at all levels of the curriculum. "The purpose of the second-tier material was to guide our teachers to understand where they could go to, to help them create difference in their spaces" (Mātanga 1). This theme highlights the importance of providing support, resources, and training to educators to ensure that they can deliver the curriculum in a way that resonates with students and promotes their success. By investing in educators' professional development, the curriculum can be effectively implemented to provide a culturally responsive and empowering educational experience for students.

One of the yet unresolved issues is the debate on what constitutes an Indigenous philosophy of Hangarau. From the perspective of the mātanga, the philosophy of Hangarau, is firstly about ngā taonga tuku iho [ancestral wisdom and traditions], recognising the need for a balance between traditional Māori knowledge and evolving Māori knowledge, and considering what knowledge is the most relevant to this generation of learners (Ministry of Education, 1999-2000a, 1999-2000b, 1999-2008, 2007-2009; 2008-2010; 2003-2012). "What informs your knowledge base? How you live your life and the knowledge you bring from your tūpuna [ancestors]" (Mātanga 2). Mātanga 2 aimed to ensure that the next generations learned at school:

> *how clever our tūpuna were… [For example] with the maramataka [Māori divisions of time] … Night after night, morning after morning, looking here, seeing what's happening here, linking it all together. That development was stunning, how they interpreted their world.*

The ongoing disruption of ngā taonga tuku iho [ancestral treasures passed down through the generations] because of colonialism required creative approaches in re-building the knowledge base. Mātanga 4 spoke of the approach used by Hirini Melbourne, who was one mātanga who worked tirelessly in re-building the puoro [music] knowledgebase, linking this approach to the ways mātanga Hangarau worked in the 1990s and 2000s: "They worked out that you could do that if you listened to lots of people, because everyone had a piece of the knowledge." This valuing of the knowledge that tūpuna [ancestors] had did not equate to knowledge being frozen in time and stuck in the past. The preservation of mātauranga Māori was one of the key goals of a decolonising curriculum. The nature of a knowledgebase is that it changes in relation to changing ideas, processes, ways of being. But the knowledge needed to be reclaimed before it could be reframed. Mātanga 1 explains the links between past, present, traditional, and 'technical' through reference to the metaphor that was used to structure the 2008 iteration of the Hangarau curriculum:

> *When you look at the Hangarau learning area with the moki [a species of blue trumpeter fish] and the fact that the moki is sitting on a whāriki [woven flax mat] and the whāriki is wrapped around it. So the moki is our subtle recognition of the mātauranga [knowledge] that we have and how that mātauranga is wrapped with the whāriki and brings in the modern day, the technical concepts but also things from our tūpuna [ancestors].*

The philosophy of Hangarau emphasises ethical decision-making, critical thinking, and sustainability. "Just because you can make it, doesn't mean it's right" (Mātanga 1), also raised by Mātanga 5: "What's the need, as opposed to, what's the want?" Mātanga 3 concurs, saying: "You can't separate technology from the impact it has on the environment". Mātanga 4 extends in explaining that the environment is considered in conjunction with people: "You couldn't do anything without having a social conscience. You always must think about your people, basically, as Māori. Whether you're needed or not, that's how we are". Mātanga 2 explains that as a Māori Hangarau practitioner, the Māori lens shapes the decisions you would make by sharing the example of having a power dam on the banks of the Waikato River (the river being an ancestor): "You would look at some other solution in order to do what you wanted to do, to get the outcome that you wanted".

Indigenous philosophies of education often emphasise holistic approaches to learning that encompass spiritual, cultural, social, and environmental dimensions (Trinick & Heaton, 2020). A curriculum philosophy that embraces this holistic perspective promotes the integration of Indigenous knowledge systems, languages, and cultural practices across various curriculum areas. It ensures that the curriculum is coherent and interconnected, fostering students' holistic development and well-being. Hangarau emphasises a holistic approach and is not static, but a whole creative process. It is not a standalone subject, but rather it is interconnected with other learning areas.

> *It was about every process, every system, every way of operating, of making, of developing how even society works around a technology… I got excited because I saw it was one of the best ways that we could engage children in learning. (Mātanga 4)*

Mātanga 2 extended this thinking by talking about the strong connections between Hangarau and Pūtaiao [Māori-medium Science].

> *They should be able to be taught together. To me, the main thing is about valuing mātauranga Māori [Māori knowledgebase] and all that that means. The key idea for me is about the knowledge that our tūpuna had to change and develop all the time, take on new ideas, work out what's right and what's wrong. It wasn't a magical thing. It was a clearly thought-out process.*

As noted, initially, in the inaugural development in the 1990s, there was a requirement to mirror the design of the English-medium curriculum, Mātanga 3 advocates as a starting point: "We have to decide whether we're going to accept the categories of Western divisions of knowledge". Once this decision is made, mātanga can either deliberate on the nature of Hangarau as a discipline, or they can interrogate "how Māori categorise knowledge traditionally and what it means in the contemporary world". Mātanga 2 agrees that there needs to be a more holistic approach to the curriculum: "I think that knowledge has been so disparate and separated as if there is a boundary, and that's what I think we're moving towards with the new Marautanga [Curriculum]". This debate on what is relevant for schooling and the categories of knowledge that have relevance to schools will (hopefully) now be in the hands of the Māori communities who should be the ones deciding about the future for their next generations.

The front section of Te Marautanga o Aotearoa [TMoA] articulates the underlying beliefs, values, and theories guiding the development and implementation of TMoA. In this section, the importance of genealogical connections is emphasised, with the hope that students in Aotearoa NZ "always remember that they never stand alone" (Mātanga 1).

When talking about the second iteration of the Hangarau curriculum, or the re-design in the mid-2000s, Mātanga 3 said: "There was a genuine attempt to indigenise the curriculum [but] I don't think we were as successful as we would have liked." Each mātanga had a complementary focus when speaking of the ways in which the 2017 iteration of the Marautanga Hangarau reflects Indigenous knowledge and pedagogy. Mātanga 4 saw Hangarau as an encompassing curriculum with significant potential for cross-curriculum integration of learning, Mātanga 1 focused on its relationship with other learning areas, and Mātanga 2 on how Hangarau is strongly linked with Pūtaiao [Māori-medium Science]. Mātanga 5 focused on the decolonising nature of Hangarau, and Mātanga 3 spoke of creativity and the potential for Hangarau to enhance lives.

Hangarau is about solving problems in a practical way. "We recognised people who were good with their hands were also knowledgeable" (Mātanga 4). It is about the holistic interconnectedness of knowledge and the need to interconnect different areas of learning. It is about creative processes, critical thinking, and sustainability.

> *Even though we're still working in Pāngarau [Māori-medium Maths] and Pūtaiao [Māori-medium Science]—I think the next step really is to have no boundaries and just have a think about that broad thing about what we want our kids to know." (Mātanga 2)*

Hangarau has a whakapapa [pedigree, ancestral lines, and connections]. Mātanga 4 raised a caveat regarding the removal of the context named Tuku Mōhiohio [Information Transfer] to facilitate the addition of the Hangarau Matihiko [Māori-medium Digital Technologies] content in 2017:

> *If you name something, it has presence (and mana). If you take things out, then it loses that and then it just becomes not that important, even though it's meant to be woven through everything, do we really understand what weaving it through looks like… and has it been researched?*

Mātanga held similar views on the place of Pākehā [Europeans] or wider western ideas in relation to Hangarau. Mātanga 1 looked at Hangarau as part of the wider curriculum, where collectively "the mātauranga [knowledge] that [students] will have access to through this Marautanga, through this curriculum, will come from a Mātauranga Māori perspective and a Western worldview perspective" (Mātanga 1). Mātanga 3 identified tensions in this when looking at "the commodification of ideas or… how you capitalise on people's needs". It is about developing a hybrid of Māori and Western ideas and finding a way to include both. It involves critical analysis between pillars of knowledge and determining what is important for students to know and be able to do (Mātanga 2, Mātanga 3, Mātanga 5). It is about reclaiming and celebrating Mātauranga Māori that is being passed down through the generations. It is also about preserving and valuing Mātauranga Māori while incorporating selected Western ideas. Mātanga 4 spoke of the need to establish connections to valuable knowledge, integrating it into your knowledgebase.

Indigenous leadership in language and curriculum emphasises the significance of whakapapa, encompassing naming and framing practices. This approach fosters the empowerment of the next generation by imparting relevant, interconnected knowledge. These elements ensure that the Hangarau curriculum acknowledges and reflects Indigenous philosophies and pedagogy. The philosophy of Hangarau as it stands currently holds much of value for Māori communities. That's not to say that its boundaries couldn't or shouldn't change in the redevelopment over 2024-2025. Hangarau is currently about solving problems, meeting needs, and in so doing, improving lives. No matter how the shape of the curriculum changes, there needs to be a focus on localising the national curriculum and significant governmental support for schools to develop their own localised curriculum, which will be explored more in relation to the discussion on the implications for classroom implementation.

Implications of Alignment on the Implementation of Hangarau

The issue of alignment and curriculum coherence significantly impacts the implementation of curriculum and classroom practice in Indigenous schools, particularly so student learning outcomes. The lack of alignment and coherence in the curriculum can lead to confusion and inconsistency in its implementation. Teachers may struggle to integrate disparate or conflicting curriculum materials, resulting in fragmented instructional approaches. This can undermine the effectiveness of teaching and learning in Indigenous schools, impeding students' ability to make meaningful connections between concepts and develop a deep understanding of the content.

Curriculum in Indigenous schools must reflect the cultural values, knowledge systems, and languages of the communities they serve. Lack of coherence between the curriculum and Indigenous cultural contexts can lead to cultural dissonance for students, as they may struggle to see themselves reflected in the curriculum or find relevance in the content. One of the identified tensions in Māori curriculum design is based on the creation of a national Māori identity in relation to Pākehā [Europeans]. Pre-contact, the hapū [extended family] was the political unit. As such, each hapū and their wider iwi [tribe] have their own practices, their own traditions, their own protocols. This cannot be accurately reflected in a nationally mandated curriculum (Mātanga 1, Mātanga 2, Mātanga 5; Ministry of Education, 2003-2012).

> *The curriculum ought to be the guide. Schools need a guide. Teachers need a guide… But I think there should have been much more support, development, discussion, critique gone into developing localised curriculum, which, in turn, or if you like, localising the national curriculum. … The responsibility for implementation, teaching, evaluation needs to shift much more to the local community. …. it can't happen without considerable support from the state (Mātanga 3)*

In summary, the issue of alignment and curriculum coherence profoundly impacts the implementation of curriculum, classroom practice, and student learning outcomes in Indigenous schools. To address these challenges, it is crucial to develop culturally responsive, coherent curriculum frameworks that honour Indigenous cultural identities, promote equitable access to resources, and support meaningful engagement and learning for Indigenous students.

Future Curriculum Alignment and Cohesion

The analysis of the dataset and the resulting discussions that were outlined briefly above have been used in the development of key recommendations to consider in the design of curriculum and its support materials for Māori-medium educators, and specifically for the Hangarau curriculum. Considering the weaknesses in curriculum coherence, it's imperative to address these issues for effective curriculum alignment and cohesion. Firstly, there is a need to address the considerable inequity in support materials that are available, particularly for teachers of students at secondary level (aged over thirteen years of age) (Ministry of Education, 1999-2000a, 1999-2000b, 1999-2003, 2003-2012, 2007-2009, 2008-2010). Providing comprehensive support materials is crucial for successful implementation of Te Marautanga o Aotearoa in Māori-medium classrooms.

Secondly, curriculum support materials should be developed bilingually and with a te ao Māori lens [a Māori worldview]. If Māori-medium is to claim the right to indigenise Hangarau (whether the boundaries of Hangarau change over 2024-2025), and other Wāhanga Ako [Learning Areas, or disciplines], then it needs to be given the opportunity and the space to develop Hangarau without its design being determined by the needs of the English-medium sector. The Māori-medium sector should determine their educational needs.

Furthermore, curriculum design for small, limited capacity communities must be flexible and tailored to their specific needs, not one size fits all. What is appropriate for the New Zealand

Curriculum should not be the reference and determine what is appropriate for Te Marautanga o Aotearoa.

If we are to consider the imbalance between demand and supply – the small pool of mātanga and Hangarau practitioners with the requisite skills and the corresponding requisite fluency in te reo Māori [Māori language] – we need to develop online materials that can be accessed asynchronously. This collective pool of resources would reduce the burden on educators to create their own materials, particularly those lacking fluency in te reo Māori.

Lastly, it's essential that theories and rationale that are being used to determine both curriculum and its support materials should be informed by systematic research in Māori-medium contexts. This research should underpin the development of both curriculum content and support materials to ensure their effectiveness and relevance within Māori-medium education.

Initial Conclusions

In conclusion, this exploration into the coherence of Hangarau curriculum development in Māori-medium education reveals the intricate interplay between Eurocentric ideologies and Indigenous aspirations. Through insights shared by curriculum experts, the transformative power of language revitalisation efforts has been underscored, not merely as linguistic endeavours but as acts of reclaiming ancestral knowledge and restoring cultural connections. Furthermore, the call for curriculum coherence resonates not only as a pedagogical imperative but as a moral imperative rooted in self-determination. Empowering Māori-medium educators to shape Māori-medium curriculum without being bound by the dictates of the English-medium paradigm is essential for fostering authentic representation and relevance.

In navigating the complexities of curriculum development, flexibility emerges as a guiding principle. Embracing bespoke approaches tailored to the needs of diverse communities acknowledges the richness of Indigenous perspectives and challenges the hegemony of one-size-fits-all education models. Looking ahead, the path towards curriculum coherence demands collaborative efforts and visionary leadership. The recommendations put forth serve as signposts for action, urging policymakers and educators alike to embark on a journey of innovation and inclusivity. By harnessing the collective wisdom of our communities and embracing the dynamic nature of knowledge transmission, we pave the way for a curriculum that truly reflects the aspirations and values of Aotearoa NZ's diverse Māori-medium educational contexts.

In closing, let us heed the wisdom of our ancestors and the aspirations of our tamariki [children]. Let us strive not only to teach but to empower, not only to transmit knowledge but to nurture wisdom, and not only to preserve culture but to cultivate its flourishing. In doing so, we honour the past, embrace the present, and forge a brighter future for generations to come.

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29.2

Reinventing Secondary School through design: An investigation of a Polytechnic High School Model focused on industry/community-driven design projects

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Abstract

This study examines the impact of a polytechnic high school model designed in collaboration with a research-intensive university and industry/community partners. Aimed at urban settings and focused on minoritized youth, this model replaces traditional subject-specific classes with industry-driven design project cycles. As design-based integrated STEM learning gains global traction, this research offers valuable insights. Pre/post surveys administered to seniors and teachers, along with follow-up surveys and focus groups with alumni during their first semester of college. This study explores the model's effect on college and career readiness, teachers' perceptions of its effectiveness, and challenges encountered in implementing design-based instruction. Through an exploration of the model's successes and challenges, this study provides actionable recommendations for polytechnic models, contributing to the broader discourse on design-based STEM instruction.

Keywords

Design-based learning, Secondary School Transformation, Integrated STEM Education

Introduction

Calls for a reformation of secondary education in the United States persist among higher education institutions and employers, aiming to align learning with the evolving demands of our society (Indiana Commission for Higher Education, 2020). Growing concern that high school graduates lack adequate preparation for college and are out of sync with anticipated workforce requirements. The traditional high school paradigm, characterized by fixed schedules, rote memorization, teacher-centered instruction, and standardized curricula, seen as ill-suited for success in contemporary society and the professional arena (Casner-Lotto & Barrington, 2006). This conventional "factory model of education," described by Serafini (2002) as treating students as products and structuring education, accordingly, not originally designed to foster critical thinking, creativity, problem-solving, or other 21st-century skills (Wheatley, 2015). Employers echo these concerns, perceiving a deficit in crucial workplace competencies among students, including communication, creativity, and critical thinking (Casner-Lotto & Barrington, 2006).

Secondary education provides students with a universal foundation of learning through curricula designed to help every student achieve similar levels of understanding or designated learning outcomes (Leland & Kasten, 2001). To achieve these learning outcomes, schools have established disciplinary silos for teaching subjects like mathematics, science, history, and language arts. This siloed approach has been the dominant way that schools function and curricula have been structured. However, this siloing of disciplines can deprive students of opportunities to make valuable and authentic connections between subjects while in school (Kirwan et al., 2022). According to Kirwan et al. (2022), the siloed educational system can cause inefficiencies in developing well-rounded and thorough instructional resources and curricula, which can directly impact student learning. This situation can be particularly challenging for schools serving diverse student populations, where traditional educational approaches may not align effectively with local cultures and communities (Paris, 2012).

Today, the challenges our world faces have become more complex, and education can be the key to developing the necessary skills students will need for their careers and lives to work toward these complex problems in the future (Hodge & Lear, 2011). For example, the 2020 STEM education visioning report published by the National Science Foundation highlights the goal of creating transformative learning experiences that involve innovative ways to work across disciplinary silos to solve big challenges. This approach is argued to help ensure that high school graduates are adequately prepared for college/careers and are not “out of sync” with anticipated workforce requirements. It is believed that these transformative learning experiences can prepare students by enhancing their “21st-century skills” (Partnership for 21st Century Skills, 2013) such as creativity, communication, and collaboration abilities.

In alignment with these demands, there has been an increased emphasis on integrated STEM (science, technology, engineering, and mathematics) programming and initiatives in secondary schools (Yuxin & Williams, 2013). Design-based learning has emerged as a common pedagogical strategy to integrate the STEM disciplines in schools (Wells & Van de Velde, 2020). This strategy involves planning instruction in a way that allows learners to activate their prior knowledge and construct new knowledge through the practice of designing solutions to problems (Strimel, 2023). However, creating authentic learning experiences that involve innovative ways to work across disciplinary silos in the resolution of meaningful and relevant problems is an organizational challenge, as schools are not typically structured in a way that allows this to occur (Strimel, 2023).

One innovative response to these challenges is the development of the polytechnic high school model, which was created to challenge the traditional siloed, factory model of education. The polytechnic school model, implemented as urban STEM-focused charter schools, has been established through collaborations involving state universities, local governments, industry leaders, and community stakeholders. The polytechnic high school model emphasizes personalized, experiential learning within an integrated STEM framework, encouraging students to pursue their passions across academic disciplines through real-world projects and design challenges conducted in partnership with industry. This approach, labelled as "polytechnic," integrates technological concepts with relevant industry contexts. Developed in collaboration with their university partner, this school model prioritizes instructional practices that foster innovation, collaboration, and creativity among diverse student groups, aiming to address real-world problems with novel solutions.

With the implementation of this new school model, there was an opportunity to learn more about attempts to "reinvent secondary schooling” through a model centered around industry/community-driven design projects. Therefore, this study delves into the innovative polytechnic school model, a partnership between a public research-intensive university and various industry and community collaborators. Here, design project cycles, created in conjunction with local partners, take center stage in instruction, replacing traditionally siloed, subject-specific classes. Given the global emphasis on integrated STEM learning through design projects (Strimel, 2023; Wells & Van de Velde, 2020; Yuxin & Williams, 2013), exploring this polytechnic school model and its design-based approach offers valuable insights toward enhancing STEM education opportunities and design-based teaching.

Table 1. Skills Emphasized in Polytechnic Education and Training (Mercer & Ponticell, 2012).

Focus Areas
• Emphasis on science, technology, and professional and technical programs, complemented by arts, humanities, and social sciences
• Smaller class sizes
• Integrated curriculum, practical and theoretical exercises throughout programs
• Hands-on, project- and team-based learning environment
• Applied, collaborative research and technology transfer
• Cross-disciplinary and co-curricular experiences, internships, and service learning
• Social responsibility
• Civic engagement
• Innovation and entrepreneurship
• Leadership in scientific, economic and community development
• Adaptation/responsiveness to needs/demands of business, industry and society

Background of Polytechnic Models

Various forms of relationships between schools, universities, and communities abound today, serving diverse purposes. Collaborations among educational institutions spanning elementary, secondary, and higher education, and with communities, have long been advocated. For the model examined in this study to qualify as a school-university collaboration, collaborative efforts must involve both institutions—the polytechnic model and the university—rather than being driven solely by individual teachers or staff members at each institution. Polytechnic schools, also referred to as practical arts institutions by Brint et al. (2005), are characterized as offering a "practical/occupational" educational approach (Mercer & Ponticell, 2012). Mercer and Ponticell (2012) outline a polytechnic educational model that highlights: a campus environment fostering interdisciplinary collaboration, utilization of innovative instructional technologies, experiential and applied problem-based learning, emphasis on applied research, convergence of disciplinary approaches, and active engagement with local and global communities, aiming to demonstrate sustainable educational and economic progress. Moreover, polytechnic educational models are noted for their emphasis on integrated STEM education and pedagogical approaches centered around student-centered, experiential learning. The goal is to equip individuals for knowledge-based economies by bridging education with industry (Mercer & Ponticell, 2012). Ultimately, polytechnics share common missions that blend theory and practice to address real-world challenges and cultivate skills essential for the contemporary workplace (Mercer & Ponticell, 2012). Table 1 illustrates some of the skills highlighted in polytechnic education (Mercer & Ponticell, 2012).

Study Context: Polytechnic High School and University Collaboration

Overview

A flagship research-intensive university, in collaboration with the largest city in the state, has established a distinctive polytechnic school-university collaborative model. The school model in this study comprises a network of STEM-focused public charter high schools (grades 9-12, ages 13-18) designed to equip students with the skills required for success in college and careers within a constantly evolving workforce. Introduced in August 2017, the school model was established with the following objectives: 1) to prepare underrepresented minority students for STEM careers, 2) to foster academic excellence and college readiness through experiential learning, and 3) to offer a comprehensive and equitable education to all students, irrespective of their academic achievements or socioeconomic status. By 2021, the model had expanded to encompass three campuses situated in urban areas throughout the state. Within this model, excellence and readiness are cultivated through a STEM-focused, project-based, experiential learning approach. Students engage in solving real-world problems through design challenges partnered with industry, embodying the essence of a "polytechnic high school," which emphasizes the application of technological concepts alongside arts and sciences within relevant industry contexts. Furthermore, the teachers at the polytechnic schools, referred to as coaches, collaborate with industry/community representatives to create design cycles that align with academic standards and provide students with rigorous STEM activities that reflect real-world problems or opportunities.

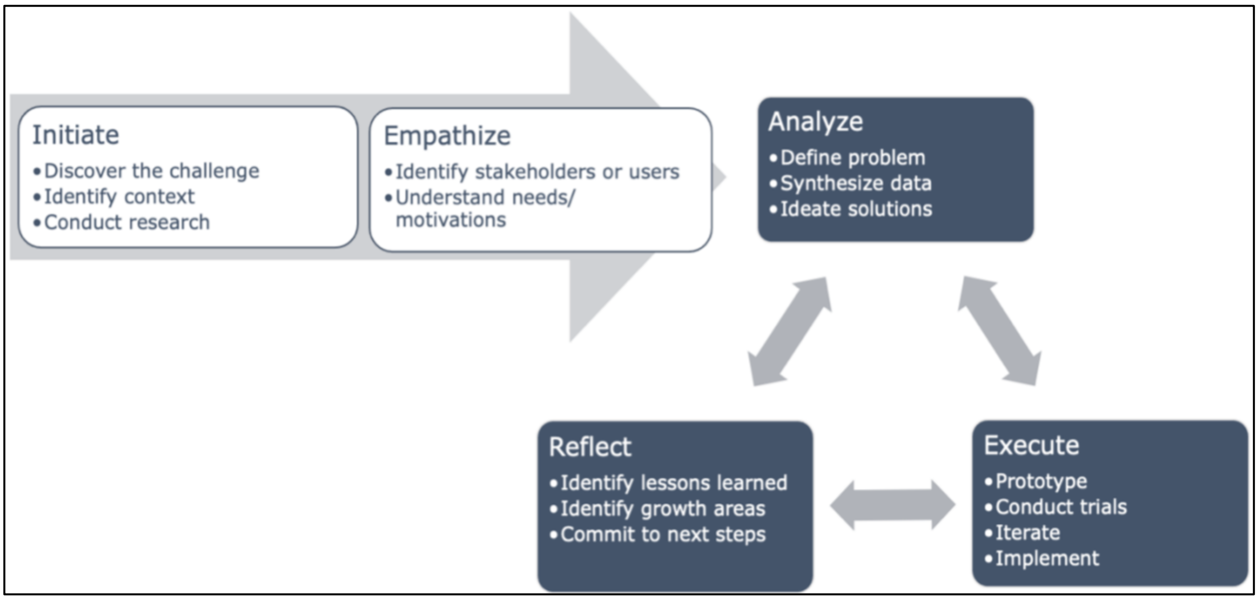

Figure 1. The Polytechnic High School Model Design Process.

Utilizing the Engineering Design Process in Industry-Partnered Projects

Developed in collaboration with the university's technology-focused academic unit, the model fosters innovation, collaboration, and creativity among diverse interdisciplinary groups, striving to devise novel solutions to real problems through their engineering design process (see Figure 1). What sets this school model apart from traditional educational models is its industry-driven and personalized approach to learning. Rather than delivering courses in conventional subjects such as mathematics, science, and language arts, students acquire desired concepts and skills through industry-partnered design challenges and student-centered passion projects. To facilitate this, the school operates on 6-week project cycles (see Figure 2), each commencing with a new design challenge partnered with an industry entity and concluding with an idea pitch to that partner. These design challenges integrate state academic standards, prompting students to tackle challenging questions, develop prototypes, and craft business models. At the end of each cycle, student teams pitch their solutions to a variety of school, community, and industry stakeholders. This design-based learning approach encourages students to solve authentic, complex, and multifaceted problems.

Figure 2. Example Design-Cycles

Polytechnic Model Day-by-day

In contrast to the common eight, subject-specific class periods (Canady & Rettig, 1995) or four-by-four class block (Jenkins et al., 2002) daily schedules found in many schools, students in the polytechnic model engage in designated "design time" and learning "dojos" throughout the week. Design time is specifically set aside for students to work on the industry-driven design challenge for the current design cycle. Dojos, in this polytechnic model, are intimate group sessions targeting specific subjects, where students can participate voluntarily or by invitation. During dojos, students collaborate with teachers to delve deeper into subjects or address issues related to the design cycle. Outside of these sessions, students have Personal Learning Time (PLT) to independently navigate modules within an online learning platform. The PLT is established to help students demonstrate specific competencies desired by the school as well as state standardized assessments. The idea is that this PLT allows students to advance at their appropriate pace through the desired content and competencies rather than moving along at the same speed as a cohort of students based on their age. Most of the PLT incorporates an online learning platform component, constituting up to 50% of the students' progress in learning, with teachers offering support as needed during independent study periods. Another distinctive feature of the polytechnic model is its emphasis on passion projects, wherein students select projects to work on that are either designed by teachers or proposed by the students themselves. These projects provide another way for students to demonstrate mastery of the school's desired competencies, enhance their autonomy in learning, and connect with teachers. All these approaches involve integrating various innovative educational strategies within the school model. Lastly, it is important to note that students who graduate from the model with a specific grade point average and a specific score on a college entrance exam are granted direct admission to the collaborating university.

Research Questions

The polytechnic high school model is positioned to provide an innovative approach to education that addresses the demands for 21st-century skills and achieves integrated STEM learning through a non-siloed approach centered on industry/community-driven design cycles. An exploratory study on how this school model was implemented and its potential influence on student learning provides an opportunity to enhance our understanding of school-wide transformation efforts emphasizing integrated STEM learning through design-based teaching. Consequently, the following research questions were developed to guide this study:

- What are the influences of a polytechnic high school model, centered on industry/community-driven design challenges, on student learning (i.e., 21st-century skills, sense of belonging, and college/career intent) as perceived by the students and teachers?
- What are the challenges and successes of a polytechnic high school model, centered on industry/community-driven design challenges, from the perspectives of teachers, students, and alumni?

Methods

Study Design

To address research question 1, data from the 2020-2021 school year were sourced from a beginning-of-year survey at one school location and pre/post-surveys administered to teachers and the first set of alumni, both before and after their first semester at the collaborating university. Surveys included Likert-scale items and open-ended questions to assess 21st-century skills (Creativity, Communication, Collaboration), sense of belonging, and college/career intent. Likert-scale items were adapted from Kelley et al.'s (2019) 21st Century Skills Survey and Anderson-Butcher and Conroy's (2002) Belonging Scale, which were validated for reliability. Open-ended responses provided a holistic view of student and teacher perceptions.

To address research question 2, focus group interviews were conducted with alumni who attended the collaborating university after their first semester. The interviews, along with teacher survey responses on the polytechnic model's challenges and successes, were recorded, transcribed, and analyzed using thematic coding (Saldaña, 2021) to extract key themes on the successes and challenges of the school model.

Survey Instruments

The teacher and student surveys consisted of 24 Likert scale items across four subscales: Creativity, Communication, Collaboration, and Belonging. The 21st-century skills (Creativity, Communication, Collaboration) were measured using items adapted from Kelley et al.’s (2019) 21st Century Skills Survey, while the Belonging subscale used five four-point items from Anderson-Butcher and Conroy’s (2002) Belonging Scale. These items help assess program impact and predict attendance patterns. Anderson-Butcher and Conroy's scale, validated with participants aged 9 to 18, demonstrated high reliability (α = .96) and was deemed appropriate for the study's alumni, despite their older age.

Table 2. Alumni Open-ended Response Questions

Pre-Survey	Post-Survey
What did you like most about your past school year at your high school?	What did you like most about the past semester at the collaborating university? Why?
How would you describe your high school to other students? What would you feel the need to tell them?	On a scale of 1-10, how well were you prepared for the learning environment here (collaborating university)? Why?
Reflecting on your experiences, what could make a student a good fit for your high school?	What were the biggest challenges with the learning environment here (collaborating university)? Why?
From attending your high school, what do you think makes you different/standout from students who attended a traditional high school?	Looking back, what would you change about your high school model?
What are you most worried about for this academic year at the collaborating university?	After being here for a semester, how did the collaborating university live up to your expectations? Why?
What are you most excited about this academic year at the collaborating university?	What do you wish you had known before making your decision to come here (collaborating university)?
	Now that you have completed a semester of higher education, what are your educational and career plans?

The 19 items measuring 21st-century skills remained consistent across all surveys, with minor adjustments to prompts based on participant groups (students, alumni, or teachers). For instance, alumni pre-surveys began with "Based on my high school experience, I am confident in my ability to..." while other surveys used "I am confident in my ability to...". Teacher surveys adapted the prompt to reflect their students' abilities. The surveys also included open-ended and multiple-choice questions to capture perceptions of the polytechnic model and, for alumni, their experiences at the collaborating university. The open-ended response questions from the alumni pre- and post-surveys are presented in Table 2.

As for the teachers' open response questions, there were two in the pre-survey asking the teachers what they are most worried about for the upcoming school year and what they were most excited about for the upcoming school year. In the post-survey administered to teachers, there were six open response questions which can be seen in Table 3.

Table 3. Teacher Open-ended response questions

Pre-Survey	Post-Survey
What are you most worried	What did you like most about this school year? How would you describe this school to other teachers? What would you feel the need to tell them?

about for this school year?	Reflecting on your experience this school year, what new challenges did you encounter?
What are you most excited for	Reflecting on your experience, what could make a student a good fit for this school?
this school year?	From working at this school, what do you think makes you different/standout from individuals who teach at a traditional school?
	From working at this school, what do you think makes you different/standout from individuals who teach at a traditional school?

Alumni Focus Group Protocol

This study's focus group design followed established guidelines from the literature. Hays and Singh (2011) emphasize the importance of selecting participants with shared experiences and equal influence over the discussion. Accordingly, all participants were freshmen who attended the innovative school model. Focus groups are typically recommended to have six to twelve participants, one to two moderators, and three to eight open-ended questions, with flexibility for follow-up queries (Hays & Singh, 2011). In line with these recommendations, our focus group included six participants, one facilitator, and five pre-determined open-ended questions:

1. How well were you prepared for the learning environment here?
2. What were the biggest challenges with this learning environment?
3. What surprised you after being here for a semester?
4. What supports would be helpful for the [high school] alum after arriving here?
5. Looking back, what would you change about the [high school] model? About the [collaborating university] model?

Findings

Research Question 1

Research question one explored the impact of a polytechnic high school model on student learning outcomes, specifically 21st-century skills, sense of belonging, and college/career intent, as perceived by students and teachers. Data from one senior class and alumni were analyzed using descriptive statistics and thematic coding, and the findings are presented by participant group (High School Seniors and Alumni). Twelve seniors (71% of the class) from one polytechnic school responded to a survey at the start of the 2021-22 school year. When asked about their post-graduation plans, seven intended to attend a 4-year college (six at the collaborating university), two planned to work full-time, and three were undecided. Figure 9 presents these responses.

The senior survey included Likert scale items across four subscales: Collaboration, Communication, Creativity (collectively 21st-century skills), and Belonging. Seniors reported the highest confidence in teamwork and decision-making but felt least confident in presenting information clearly. In terms of Belonging, all seniors felt supported by their school, though three expressed concerns about commitment, acceptance, and comfort. Two open-ended questions highlighted a mix of excitement about completing high school and concerns about graduation, with themes identified through thematic coding (Saldaña, 2021). Ten alumni (about 26% of the alumni class attending the collaborating university) completed the pre-survey before the 2021-22 academic year. Their responses are presented in Table 5.

Table 4. High School Senior Survey Responses (N = 12).

Number of Participants Selecting each Likert-Scale Response						
	Question: "I can…"	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Collaboration	Q1. be polite and kind to teammates	1	0	0	3	8
	Q2. acknowledge and respect other perspectives	1	0	1	5	5
	Q3. follow rules for team meetings	1	0	1	4	4
	Q4. make sure all team members' ideas are equally valued	1	1	1	3	6
	Q5. offer assistance to others in their work when needed	1	2	0	6	3
	Q6. improve my own work when given feedback	1	0	1	4	6
	Q7. use appropriate body language when presenting	1	0	3	3	5
	Q8. come physically and mentally prepared each day	1	2	3	3	3
	Q9. follow rules for team decision-making	1	0	0	4	7
Communication	Q10. use time, and run meetings, efficiently	1	1	2	6	2
	Q11. organize information well	1	0	2	6	3
	Q12. track our team's progress toward goals and deadlines	1	1	3	5	2
	Q13. complete tasks without having to be reminded	1	1	3	5	2
	Q14. present all information clearly, concisely, and logically	1	0	4	4	3
Creativity/ Innovation	Q15. Understand how knowledge or insights might transfer to other situations or contexts	1	1	1	4	5
	Q16. Find sources of information and inspiration when others do not	2	0	1	3	6
	Q17. Help the team solve problems and manage conflicts	1	1	2	5	3
	Q18. Adapt a communication style appropriate for the purpose, task, or audience	1	1	2	5	3
	Q19. Elaborate and improve on ideas	1	0	1	7	3
Belonging	Question	NO!	No	Yes	YES!	
	Q20. I feel comfortable at this school.	0	2	7	3	
	Q21. I am a part of this school.	0	1	8	3	
	Q22. I am committed to this school.	0	1	6	5	
	Q23. I am supported at this school.	0	0	7	5	
	Q24. I am accepted at this school.	0	1	5	6	

Participants reported the highest confidence in Collaboration skills but demonstrated varied confidence in Communication, particularly in presenting information clearly. While all felt supported at the collaborating university, some voiced concerns about commitment and comfort. Open-ended responses praised the school model for its flexibility in project choice and hybrid learning structure. Students recommended that success at the school requires dedication, independence, and adaptability. Although they anticipated challenges with workload and academic adjustments at the university, they expressed excitement about new learning opportunities and networking. Four alumni (about 10% of the class pursuing higher education at the collaborating university) completed the post-survey. Their responses are shown in Figure 11.

Table 5. Alumni Pre-Survey Responses (N = 10).

Number of Participants Selecting each Likert-Scale Response

	Question: "I can…"	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Collaboration	Q1. be polite and kind to teammates	0	0	2	0	8
	Q2. acknowledge and respect other perspectives	0	0	1	1	8
	Q3. follow rules for team meetings	0	0	0	2	8
	Q4. make sure all team members' ideas are equally valued	0	0	0	4	6
	Q5. offer assistance to others in their work when needed	0	0	1	3	6
	Q6. improve my own work when given feedback	0	0	0	3	7
	Q7. use appropriate body language when presenting	1	0	0	3	6
	Q8. come physically and mentally prepared each day	1	2	1	2	4
	Q9. follow rules for team decision-making	0	0	1	3	6
Communication	Q10. use time, and run meetings, efficiently	0	1	0	4	5
	Q11. organize information well	0	1	1	4	4
	Q12. track our team's progress toward goals and deadlines	0	0	1	4	5
	Q13. complete tasks without having to be reminded	0	0	1	3	6
	Q14. present all information clearly, concisely, and logically	0	1	0	3	6
Creativity/ Innovation	Q15. Understand how knowledge or insights might transfer to other situations or contexts	0	0	1	2	7
	Q16. Find sources of information and inspiration when others do not	0	0	1	5	4
	Q17. Help the team solve problems and manage conflicts	0	1	1	1	7
	Q18. Adapt a communication style appropriate for the purpose, task, or audience	0	0	1	5	4
	Q19. Elaborate and improve on ideas	0	0	1	3	6
Belonging	Question	NO!	No	Yes	YES!	
	Q20. I feel comfortable at this school.	0	0	5	5	
	Q21. I am a part of this school.	0	1	4	5	
	Q22. I am committed to this school.	0	1	4	5	
	Q23. I am supported at this school.	0	1	2	7	
	Q24. I am accepted at this school.	0	0	3	7	

Participants expressed strong confidence in 21st-century skills, especially Communication, and felt a sense of belonging at the collaborating university. Open-ended responses highlighted positive experiences, such as the college atmosphere and networking opportunities, but also challenges like balancing workload. Suggestions for improving the high school model included better math instruction and returning to industry-based design cycles. Expectations of the university were mixed – students praised social experiences but criticized academic organization. Many wished they had better knowledge of study skills and financial aid before enrolling. Career plans varied, including further education, internships, and entrepreneurship.

Table 6. Alumni Post-Survey Responses (N = 4).

Number of Participants Selecting each Likert-Scale Response						
	Question: "I can…"	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Collaboration	Q1. be polite and kind to teammates	0	0	0	0	4
	Q2. acknowledge and respect other perspectives	0	0	0	0	4
	Q3. follow rules for team meetings	0	0	0	1	3
	Q4. make sure all team members' ideas are equally valued	0	0	0	1	3
	Q5. offer assistance to others in their work when needed	0	0	0	2	2
	Q6. improve my own work when given feedback	0	0	0	1	3
	Q7. use appropriate body language when presenting	0	0	0	1	3
	Q8. come physically and mentally prepared each day	0	0	1	0	3
	Q9. follow rules for team decision-making	0	0	0	1	3
Communication	Q10. use time, and run meetings, efficiently	0	0	0	1	3
	Q11. organize information well	0	0	0	1	3
	Q12. track our team's progress toward goals and deadlines	0	0	0	1	3
	Q13. complete tasks without having to be reminded	0	0	0	1	3
	Q14. present all information clearly, concisely, and logically	0	0	0	0	4
Creativity/ Innovation	Q15. Understand how knowledge or insights might transfer to other situations or contexts	0	0	0	2	2
	Q16. Find sources of information and inspiration when others do not	0	0	1	2	1
	Q17. Help the team solve problems and manage conflicts	0	0	0	2	2
	Q18. Adapt a communication style appropriate for the purpose, task, or audience	0	0	1	1	2
	Q19. Elaborate and improve on ideas	0	0	0	1	3
Belonging	Question	NO!	No	Yes	YES!	
	Q20. I feel comfortable at this school.	0	0	0	4	
	Q21. I am a part of this school.	0	0	2	2	
	Q22. I am committed to this school.	0	0	1	3	
	Q23. I am supported at this school.	0	0	2	2	
	Q24. I am accepted at this school.	0	0	1	3	

Six alumni participated in a focus group after their first semester at the university, providing additional insights. They expressed confidence in the 21st-century skills gained from the high school, especially in teamwork and public speaking, but felt less prepared in traditional subjects like math, having only completed precalculus. They noted the strong alumni network helped ease their transition to college and guided their career paths, but they were concerned about competing academically and navigating financial aid.

For the teacher data, 15 teachers completed the pre-survey, and 23 completed the post-survey. Teacher experiences are summarized in Table 7.

Table 7. Teacher Survey Participants

	Years	Pre-survey	Post-survey
Teaching Experience	Less than 1	1	2
	1-3	3	4
	4-6	3	2
	7-10	2	2
	11-14	4	3
	15+	0	3
Polytechnic High School Experience	Less than 1	4	5
	1	2	3
	2	2	4
	3	1	0
	4	4	4

During the pre and post survey, results from the Likert Scale questions stayed relatively similar, with some decreases and increases in means and standard deviation. Teachers were asked to select a level of agreement to indicate how they feel about their students' abilities in areas relating to 21st century skills. The survey results are presented in Table 8 and results around teachers’ perception of student belongingness in Table 9.

Table 8. Teacher survey results related to 21st Century Skills.

Construct	Statement (I believe my students...)	Pre-Survey (*N = 15*)		Post-Survey (*N = 23*)	
		Mean	Std Dev	Mean	Std Dev
21st Century Skills (Collaboration)	are polite and kind to teammates	3.75	1.01	3.60	0.66
	acknowledge and respect other perspectives	3.50	0.96	3.80	0.40
	follow rules for team meetings	3.25	0.92	3.20	0.81
	make sure all team members' ideas are equally valued	3.08	0.86	3.30	0.71
	offer assistance to others in their work when needed	3.42	0.86	3.50	0.59
	use appropriate body language when presenting	3.42	0.95	3.15	0.73
	come physically and mentally prepared each day	2.92	0.95	2.85	0.65
	follow rules for team decision-making	2.92	0.86	3.20	0.68
	Improve my own work when given feedback	3.83	0.69	3.60	0.86
21st Century Skills (Communication)	use time, and run meetings, efficiently	2.58	1.04	2.55	0.59
	organize information well	2.83	0.90	2.85	0.73
	track their team's progress toward goals and deadlines	2.83	0.99	3.20	0.51
	complete tasks without having to be reminded	2.67	1.03	2.55	0.86
	present all information clearly, concisely, and logically	2.92	0.86	2.95	0.64
21st Century Skills (Creativity)	understand how knowledge or insights might transfer to other situations/contexts	3.42	0.86	3.05	0.74
	find sources of information and inspiration when others do not	3.33	1.03	3.20	0.81
	help the team solve problems and manage conflicts	3.42	0.76	3.05	0.74
	adapt a communication style appropriate for the purpose, task, or audience	3.17	0.80	3.00	0.77
	elaborate and improve on ideas	3.50	0.65	3.40	0.73

Note. A Likert-scale of 5-Points was used: 5=Strongly agree to 1=Strongly Disagree.

Table 9. Teacher survey results related to Student Belongingness.

Statement (I believe my students...)	Pre-Survey (*N = 15*)		Post-Survey (*N = 23*)	
	Mean	Std Dev	Mean	Std Dev
Feel comfortable at this school	3.17	0.55	3.10	0.54
Are a part of this school	3.50	0.50	3.40	0.58
Are committed to this school	2.92	0.64	2.75	0.43
Are supported at this school	3.50	0.65	3.25	0.43
Are accepted at this school	3.42	0.64	3.30	0.46

Note. A Likert-scale of 4-Points was used: 4=YES!; 3=Yes; 2=No; 1=NO!

Teachers expressed confidence in their students' 21st-century skills, particularly in teamwork and communication, but had concerns about students' time management and autonomy. Although students felt a sense of belonging at the school, some experienced declines in commitment and comfort.

Research question 1 examined how the innovative polytechnic high school model, centered on industry-driven design challenges, impacted students' preparedness for college and careers in terms of 21st-century skills, belonging, and aspirations. The data indicated that students felt more confident in their 21st-century skills but faced challenges with college readiness in traditional academic subjects due to curriculum adjustments and reliance on online supplements. Students also reported a strong sense of belonging at both the high school and the collaborating university. Additionally, the school model appeared to influence college and career aspirations by encouraging students to pursue projects aligned with their interests and seek relevant credentials.

Research Question 2

As for research question 2, to explore the challenges and successes associated with an innovative polytechnic high school model from the viewpoint of former students, a focus group session was arranged with six alumni who had completed a semester at the collaborating university. As for the teacher's perceptions of the successes and challenges, the post-survey data was analyzed. The following themes were derived from the participants' perspectives on the model's challenges and accomplishments.

Alumni Focus Group Challenges

Alumni challenges were identified as 1) Academic Preparedness (Mathematics), 2) Personal Learning Time Purgatory, and 3) Innovation for the Sake of Being Innovative. These themes are detailed below, with supporting comments from participants responses collected during the focus group. As a note, all comments were transcribed verbatim, and therefore may have grammatical errors, repetitions, or filler words. The literature documenting guidelines for conducting focus groups and analyzing the resulting data emphasized the importance of verbatim transcriptions in order to fully, and more accurately, capture participants' perceptions (Hays & Singh, 2011).

Academic Preparedness (Mathematics).

Participants perceived their academic preparedness as mediocre, specifically after they had transitioned to the collaborating university. It is important to note that participants themselves decided to make a distinction between being "*academically prepared*" and being "*prepared in* *other ways,*” which is discussed more in the successes section. All participants within the focus group rated their academic preparedness a “5” or “6” (on a 10-point scale). For example, one participant mentioned “*academically, math wise, all these different things... I feel like I was not prepared at all.*” Naturally, participants discussed the challenges they faced with the academic environment that had been provided by the high school model, specifically describing the school subjects as being “*underserved,*” especially mathematics, which students perceived to be “*incredibly underserved and not prioritized nearly enough*.” Another participant shared this sentiment, saying; “*My other subjects were not very technical, so I guess it wasn't as difficult, but math is —definitely was —it wasn't structured as well.*”

Participants mentioned several reasons for this perspective, including the school model’s approach to “*traditional subjects*” which initially entailed students completing modules for mathematics courses through an online learning platform, during their Personal Learning Time. One student described the difficulty of the online learning supplement approach, stating: “*I think that it was a hindrance when it came down to it and they needed to put more time into traditional teaching structures for math, I believe*.”

Based on their responses, the school model eventually shifted to completely 50% online, and 50% project-based before the students’ junior year in high school, which contributed even more to students' poor perception of the model’s approach to traditional academics, and of their own academic skills. While participants readily discussed their views on their academic readiness, they appeared even more inclined to propose potential remedies for the obstacles encountered. For example, students stated: “*AP classes, honors classes. That would be very helpful because I know a ton of people, they took AP classes, and they get to skip a bunch of stuff. And I'm stuck in the bottom,*” with another participant following this statement by saying, “*honors classes and AP classes would definitely help a lot.*”

At the university level, participants recommended transitioning from scantron exams for mathematics courses to traditional-style tests to allow for partial credit opportunities. This shift would enable the recognition of students' efforts and problem-solving approaches, rather than solely relying on scannable answer sheets. One participant expressed frustration with the current system, stating: "*If you hear me out, partial credit on math. So, they do Scantrons — Wrong answer, wrong bubble. Yeah, even if you did it right even until the very last moment.*" While acknowledging that implementing this change might necessitate hiring more teaching assistants for exam grading, participants believed it would result in fewer students failing mathematics courses.

Personal Learning Time Purgatory.

In the school model, Personal Learning Time (PLT) refers to the designated period for students to independently engage with modules (each covering various subjects and accessible through the school's online learning platform) while receiving support from teachers as required. During the focus group, participants conveyed how what initially resembled "just a study hall" with a "work at your own pace" philosophy gradually evolved into a "purgatory" of unstructured hours during the school day. They detailed several challenges associated with this approach, citing instances where they were unsure of what tasks to undertake, occasionally found themselves lacking assignments, experienced reduced motivation to work due to the flexible pacing and lenient deadlines, and felt burdened by the sometimes-unrealistic expectations placed on students during this period. For example, one participant described their experience in PLT during their senior year, stating: *"Moving through, especially in my senior year, I got to a point where, where the workload was still pretty heavy. But I was able to get it done in a reasonable amount of time that I just had this PLT time where I just kind of had nothing to do"*.

One student described PLT as, "*Just big 4-hour blank spaces that you would sit down and work, but — like hell*" while another described the model's approach to PLT, saying it was like: "*I'm gonna put you in a pool and hope you swim.*" Lastly, the model's "*go at your own pace*" approach to learning during this time, was "*kind of what bit some people in the ass*" when it came to meeting deadlines. Participants provided possible solutions to combat these challenges, such as providing more defined structures during PLT ("*just add some more structure, more classroom —not like —more support from the teachers*"), allowing students to return to personalized scheduling, and aiding students in "*learning self-discipline*" (including "*deadline responsibility*").

Innovation for the Sake of being Innovative.

The innovative nature of the high school model necessitated various new educational approaches to achieve its objectives. While participants appreciated several innovations like industry partner projects and passion projects, they also critiqued the model's tendency to sometimes prioritize innovation without clear purpose. They pointed out what they perceived as unnecessary innovations, such as competency grades and the substitution of traditional classes with online learning supplements. One participant expressed frustration with the absence of traditional courses within the model, *stating: "I felt like the lack of any traditional classes was unnecessary.*" One student described their frustration, saying: "*Don't just not have traditional classes because traditionalism is terrible. You know, it's been working. There're parts of the traditional learning model that obviously work. We see it in our college lecture halls. We see it in all the schools around the world, you know —parts of our learning style are still very effective, you know?*"

Another participant believed the model competencies were an unnecessary innovation within the model, describes this view, saying: "*They have competencies —were in those projects. They have like three competencies —like three, like focus areas that they have, and there's 20 total. And you can either get like an A, B, C, or like a non-completion F grade for uhm—I hate that idea. Because it's just another kind of grade that they have to —you have to focus on other than the traditional grade that they have for in [ONLINE LEARNING PLATFORM].*" Although respondents seemed to believe there were unnecessary innovations within the school model, students took time to provide some suggestions for addressing this challenge. For example, regarding the online learning platform used for all core classes, participants suggested a blend of the use of the online learning platform and traditional courses, while also keeping the model's focus on industry partner challenges and passion projects. One student described this approach, saying: "*So, bring that back for math and all of these other largely knowledge-based subjects and still keep the project cycles there. You know, the project cycles are really what gave me all the critical thinking skills that I have today.*"

Another respondent agreed with the blended approach, saying: "They need to —yeah, they need to add traditional classes for like math and some sort of sciences. But they also, I think they—I do like the projects that the teachers set up."

Another participant then agreed with this, stating: “So, I think they should, they should keep [PASSION PROJECTS] but also try to fit in the traditional stuff as— as well. And not just have those online, and ‘just if you need them well, you can just schedule it—If you need them. Just we'll —just have you, you know, do it online all the time.’ Because I think the projects are a good idea.”

Regarding the competencies, respondents believed it was an unnecessary part of the model. One student described their solution, “T*hey need to get rid of that.*” Ultimately, participants believed the model had many great components, but the model needed to “*kind of go back a little bit stop trying to be so needlessly innovative, I think, and they have a great school.*”

Alumni Focus Group Successes

During the focus group, participants also took time to describe some of the successes they experienced, through attending the school model, and once they had transitioned to the university. Several themes related to student successes were identified, including 1) There's More than One Way to Measure Success, 2) School Model Pedagogies, and 3) No Regrets.

There's More than One Approach to Success.

Participants in the focus group made a clear distinction between being "*academically prepared*" and being "*prepared in other ways.*" While they acknowledged feeling less prepared academically due to their attendance at the innovative school model, they emphasized the non-academic successes the model offered them. One participant expressed this sentiment, stating, "*I still think that we are prepared a lot of other ways*." Interestingly, all participants rated themselves higher in terms of being "*prepared in other ways*" compared to their academic preparedness. For instance, one participant highlighted the importance of the model's emphasis on self-responsibility, stating: "*It kind of taught you a lot of self-responsibility.*" Others echoed this sentiment, citing skills such as time management, self-advocacy, and social interaction as areas where they felt confident. These skills were often linked to the unique opportunities provided by the school model, such as project cycles and online learning platforms. One participant even attributed their critical thinking skills to the project cycles, stating, "*the project cycles are really what gave me all the critical thinking skills that I have today.*"

School Model Pedagogies.

Despite some challenges, participants recognized several aspects of the model's pedagogical approaches as successful. They appreciated the opportunities for personalized learning, particularly through passion projects. One participant described the variety of options available, stating, "*If you want to do Ethics Bowl, or like, it's like a debate class, you could do it.*" Additionally, participants valued the freedom to create their own schedules and pursue extracurricular interests during Personal Learning Time (PLT). Some used this time for projects or career-related activities, such as IT certifications. Despite critiques, all participants expressed satisfaction with their decision to attend the model, emphasizing its positive impact on their personal growth and proactive mindset.

No Regrets.

Despite encountering challenges associated with their involvement in an innovative polytechnic school model, both during their high school years and after transitioning to higher education, participants remained resolute in their choice to enroll in the model. They intentionally concluded the focus group on a positive note, underscoring their favorable perception of the model. This sentiment was exemplified by one student's remark: "*Overall, my— because it seems like a mainly focusing on the critiques. Overall, I have mainly a positive attitude around it—it really prepared me for a lot of stuff. If I went to LOCAL SCHOOL], I don't know what kind of person I'd be but— so going to [INNOVATIVE SCHOOL MODEL], it definitely made me a greater person, a more proactive person so...* "

Other participants followed this comment by sharing a similar perception: "Yeah, and we're bashing the system, but we're not bashing — I think it was the right decision, it just could have been better."

Based on the data, participants perceived there to be advantages to pursuing a traditional high school education, however, students also believed their choice to pursue a nontraditional high school experience had its own advantages. For example, one participant describes this perspective: "So, in a way, having a more traditional school would have helped, but also, that being like, nontraditional did help, as well, because it —because it ended up forcing me to like, you know, think for myself, actually go through and ask questions, if there's something that I'm interested in, like, go and research and become —instead of just having like something you thought about for like, for like a, like a day or so, then just gave up." Despite the "risks" taken— as some students described— by attending the novel school model, all students concluded the focus group by sharing that they had no regrets in their decision to attend the model.

Teacher Identified Challenges

As for the teacher post-survey responses topics around challenges such as 1) Student Autonomy and 2) COVID-19 arose.

Student Autonomy.

Teachers observe students grappling with autonomy, noting instances of its misuse within the school model. One teacher highlighted the model's emphasis on autonomy, requiring substantial patience. The design-cycles emulate real-world problem-solving scenarios, fostering student-driven progress and necessitating a shift in the traditional teacher role. Balancing support for student autonomy demands adaptation and patience from both students and teachers. Described as a "*non-traditional school, where a lot of the student's academic work is self-paced and online, and the school day is split between some classes, independent work, and passion projects*." Therefore, "*self-motivated, driven students who can work without an adult always pressuring them to complete their work*" would be a good fit within this type of school model. However, from the teachers' responses it seems that few students are challenged to fit within this "*mold*" at their age level. However, teachers perceive that few students at their age level effectively adapt to this model's expectations.

COVID-19.

For example, it was mentioned that "*the transition from post-covid was hard*" getting back from online school to in person school came with its challenges. One of the teachers said they felt "*like they are starting from scratch in some ways*" at the beginning of the school year, coming back from online school because some students fell "*even further behind during the pandemic than other*" and another mentioned "*this was a challenge this year as we had to spend a lot of* *time on their basic tasks from a couple of years ago instead of being able to focus on grade level content and up.*" As students had their classes through a computer screen for an extended period of time, the in-person responsibilities and requirements for a design-based STEM curriculum were hard to translate in a virtual environment. This resulted in a low level of accountability for the students which challenged them in the more "*self-directed learning*" school model. It was reported that "*from over a year of COVID-learning, students are not prepared to be in a classroom and pay attention with their cell phones and other devices.*" Therefore, coming back face-to-face with students, the teachers experienced some challenges for the school model such as dealing with "*behavioural issues due to being under-socialized through eLearning*." One recommendation given by a teacher was to have a strong sense of self before teaching in this school model, knowing who you are in an educational model that demands the most from the educator was seen as advantageous in this setting.

Teacher Identified Successes

As for the teacher's post-survey responses around the successes of the school year, the following themes arose: 1) Commitment to Innovative Education and 2) Building Meaningful Relationships.

Commitment to Innovative Education.

Teachers were enthusiastic about providing students with authentic, hands-on learning experiences, integrated STEM lessons, and connections with real projects alongside industry/community partners, fostering design/project-based learning aligned with student interests. As per one of the teachers, the polytechnic model allows for "*innovation in all areas*" The teachers felt that this school provided innovation opportunities for the students within the learning experiences including innovation opportunities for teachers with decision making related to the school and the curriculum. As this model is new and striving to foster 21stcentury skills through authentic learning experiences, a teacher described this school as a "*pillar for school change*" This innovative educational model is looking to link "a*cademic connections of why we're doing what we're doing*" to bring context to problem solving through design-based learning. Additionally, the teachers are given "*creative control*" of their learning activities, and one teacher wrote "*I am flexible, innovative, collaborative*" The teachers are conveying innovation within the school and students are growing through a new type of educational experience. During the design-cycles, the teachers see their role as needing "*to be adaptable to changes throughout the design process,*" indicating that educational innovation for the teachers is constant They also noted significant progress among first-year students in their design cycle pitches/presentations. This innovative educational model encourages innovation in all areas, providing opportunities for students and teachers to engage in decision-making related to the curriculum and school operations. Additionally, teachers emphasized the importance of building relationships with students to support their understanding of their roles as valued members of society, assisting them in achieving their goals and fostering a collaborative learning environment.

Building Meaningful Relationships.

One of the common themes that teachers wrote about was their excitement to be in-person for this school year. The strain on building relationships between students and teachers was challenging during the pandemic. As one coach wrote, "*I am happy to be back in the building and able to make connections with my students not just in a virtual capacity.*" The teachers want to have meaningful relationships with their students, which is viewed as necessary to help students progress through the design-cycles and their passion projects. Additionally, teachers wrote about the school, saying that "*getting to know the polytechnic high school team, its students, and its philosophy for reinventing education*" was something that they enjoyed about the school year. Forming connections and creating relationships makes a difference in such an open-ended and self-directed educational environment. A coach wrote that "*I am happy that we are all able to get back into the building and be able to work together face to face.*" Overall, teachers were excited for the in-person school year, especially at an innovative school where relationships, innovation, and education come together for hopes of secondary educational transformation.

Summary of Research Question 2 Results

Research question 2 aimed to explore the challenges and successes encountered by students and teachers in an innovative polytechnic high school model centered on industry-driven design challenges. Analysis of data obtained from the alumni focus group and survey responses revealed various insights. Students highlighted challenges such as a perceived lack of readiness for college-level academic coursework, the presence of unnecessary innovations within the school model, and dissatisfaction with personalized learning time. Conversely, students reported successes including a sense of belonging at the collaborating university, opportunities for personalized projects aligned with their interests, increased confidence in 21st-century skills, and perceived benefits of pursuing a nontraditional high school education. While teachers struggled with student autonomy and COVID-19, there were also successes such as enjoying the ability to try innovative pedagogy, and to build meaningful relationships.

Conclusions, Discussions, & Recommendations

This study explored perceptions of an innovative polytechnic high school model regarding college and career readiness and identify its associated challenges and successes. The focus on a high school model integrating STEM experiences, personalized learning, and industry-driven design challenges, data collected from student, teacher, and alumni surveys and an alumni focus group. Findings reveal the polytechnic model, which emphasizes industry and community-driven design challenges, presents both opportunities and challenges. Participants described the model as evolving, with the metaphor "building the plane while flying it" capturing their experience. Alumni, navigating a constantly adapting curriculum, noted both positive and negative aspects. They valued personalized learning and industry connections but faced challenges in traditional academic subjects and adapting to higher education's demands. Teachers observed strong student skills in collaboration and communication but expressed concerns about time management and autonomy.

The model's strengths included fostering 21st-century skills and belonging, while its weaknesses involved challenges with traditional academics and reliance on online learning. Participants appreciated real-world project opportunities but felt underprepared for conventional academic expectations. There was a notable tension between innovative learning methods and traditional academic rigor, impacting students' readiness for standardized tests and higher education coursework.

The study highlights the dual nature of innovative educational models: they offer significant benefits in personalizing learning and enhancing real-world skills but also face challenges in balancing these with traditional academic requirements. The findings underscore the need for ongoing evaluation to determine whether the advantages outweigh the risks and to inform future iterations of such educational models.

Recommendations include enhancing communication and collaboration between high schools and partnering universities to better prepare students for higher education. This includes increased involvement and clearer communication from the university regarding academic expectations and support resources for transitioning to a lecture based higher education learning model. Additionally, refining the academic approach is crucial; addressing gaps in traditional academic preparation, particularly in math and science, by integrating more structured instruction alongside design challenges is necessary. Balancing online learning with face-to-face instruction can help with academic preparation. Future research can focus on longitudinal studies to track alumni experiences over time and explore additional perspectives from academic advisors and parents. Investigating how students from different academic paths within the university or other institutions respond to the model and studying the long-term impact of such models on educational innovation, can offer valuable insights. This study provides insights and recommendations for improving the balance between innovative learning approaches like this polytechnic model, and traditional academic requirements to better support student success in higher education and beyond.

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29.2

Development of a new framework of Technology and Engineering Education by the Japan Society of Technology Education

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Abstract

It is considered important to clarify the role of technology and engineering education for evolving STEM/STEAM education in each country. However, in Japan, unlike in other countries, the focus on STEAM education began after 2018, so the relevance of STEAM education to technology and engineering education has not yet been fully discussed. Therefore, the Japan Society of Technology Education (JSTE) tried to develop a new framework of technology and engineering education for promoting STEAM education in Japan prior to the revision of the National Curriculum. First, we conducted a survey on 1,656 Japanese junior high school students about the status of 'Technology' learning. As a result, it was shown that Japanese students have a positive attitude of 'Technology' classes. However, there is a lack of learning activities related exploring technology, and design problem-solving is not adequately linked to abilities for technological innovation and governance. From this, we developed a new framework focused on enhancing exploratory activities and problem-solving related to engineering. The framework included the Triple-Loop Model as the engineering design process, the connections between physical and cyber technologies within that scope, and the learning model of STEAM education that centred on the engineering design process with various connections among all subject areas. Lastly, we conducted a survey to evaluate the new framework on JSTE members (four-point scale, agreement rating). As a result, many received mean value of 3.00 or higher, showing that the participants agreed with the proposals. However, the concept of the term 'Engineering' (2.78) had a mean value of less than 3.00 and a larger SD than the others. Therefore, in the last version the concept of the term 'Engineering' was revised, and the framework was completed.

Keywords

The Japan Society of Technology Education, Technology and Engineering Education, new framework, Japan

Introduction

Background and purpose of the study

As STEM (Science, Technology, Engineering, Mathematics) / STEAM (Science, Technology, Engineering, Arts, Mathematics) education flourishes worldwide, the importance of technology and engineering education is increasing. The International Technology and Engineering Educators Association (ITEEA) states in the Standards for Technology and Engineering Literacy (STEL) that "Extensive changes have taken place in education in the past twenty years. There is an increased emphasis on design, and specifically on technology and engineering design, in the PreK-12 curriculum" (ITEEA, 2020, p.viii). However, the role of technology and engineering education in STEM/STEAM education is sometimes underestimated. In the STEL, it is also mentioned, "In spite of this recognition, the role that technology and engineering play, and should play, in the education of PreK-12 students is often narrowly defined and misunderstood" (p.viii). In such a situation, it is important to clearly define the role of technology and engineering education in STEM/STEAM education at an early stage for educational reform. This is one of the main reasons for the publication of STEL by ITEEA.

In the case of Japan, since 2019, there has been an increasing focus on STEAM education within the Ministry of Education, Culture, Sports, Science and Technology (MEXT, 2019). MEXT is paying attention to the characteristics of STEAM education as transdisciplinary learning that integrates STEM and Arts (MEXT 2019). Perignat and Katz-Buonincontro (2019) state there are a myriad of definitions for STEAM and the 'Arts'. One such theory is that of Yakuman (2010), who proposed STEAM education is an integrated educational theory that adds Arts to the traditional STEM education. Yakman defines STEAM as interpreting science and technology through engineering and the arts, based on mathematical elements, and she states the main objectives of this theory are as follows:

(i) Integration of Disciplines: It provides a more comprehensive education by integrating and interrelating the fields of science, technology, engineering, arts, and mathematics.

(ii) Promotion of Creativity: By incorporating arts, it enhances students' creativity and problem-solving skills.

(iii) Relevance to Real Life: It deepens the understanding of real-world problems, enabling students to tackle challenges they may face in society.

Yakman's STEAM education theory aims to eliminate the 'silo effect' of academic disciplines, fostering a learning environment where each field complements the others, thereby increasing students' interest and motivation to learn. In the case of Japan, based on Yakman's theory, MEXT defined STEAM education as "transdisciplinary learning that utilises learning from each subject to discover and solve real-world problems" [translation from Japanese] (MEXT, 2019). And they define the scope of Arts (the 'A' in STEAM) broadly, to include not only fine arts and culture but also life, economics, law, politics, ethics, and other areas of Liberal Arts.

It is highly likely that STEAM education will become an important concept in the revision of the next national curriculum in Japan. However, the approach to educational reform in Japan is unique, and there is a need to seamlessly connect the history of previous educational reforms with new concepts such as STEAM education. Therefore, it may be difficult to apply the ITEEA's STEL directly to Japan. It is likely that other countries with their own national curricula may face similar difficulties. In the context of Japan, it is necessary to have academic proposals that play a similar role to ITEEA's STEL in order to clarify the role of technology and engineering education in STEAM education.

For these reasons, the Japan Society of Technology Education (JSTE) initiated a project to develop a new framework for technology and engineering education in Japan. JSTE is an academic society that leads research in technology education in Japan. JSTE has already published "Technology Education in the 21st Century" (first edition) in 1999, followed by a revised edition in 2012, and illustrative examples of contents in 2014 as frameworks for technology education in Japan (JSTE, 1999, 2012, 2014). These documents proposed the principles, objectives, contents, and problem-solving processes of technology education in Japan. On the other hand, the revision of the national curriculum is deliberated upon by relevant subcommittees of the Central Council for Education (CCE) of MEXT, in response to consultations from the Minister of MEXT. For each subject area, specialized committees in the CCE consisting of Senior Specialist for Curriculum, university researchers, prefectural educational supervisors, schoolteachers, and other representatives are involved in the deliberations. Usually, academic societies are not directly involved in this process. However, in the case of technology education, the proposals by JSTE, such as "Technology Education in the 21st Century" (JSTE, 1999, 2012), have had a certain level of influence on the revision of the national curriculum. Ueno (2023) pointed out that during the revisions of the curriculum in 2008 and 2017, the president and vice-president of JSTE became members of the specialized committees. This inclusion facilitated the implementation of curriculum reforms based on the ideas presented in "Technology Education in the 21st Century."

Currently, discussions have begun in Japan regarding the revision of the next educational reform. It is expected that JSTE will continue to have a certain level of influence on this educational reform, like previous revisions. In fact, it has been more than 20 years since the first edition of "Technology Education in the 21st Century" was published in 1999, and during this time there have been significant changes in society and technology. Especially in recent years, there has been increasing emphasis on the Fourth Industrial Revolution and Connected Industries, highlighting the integration of new technologies such as artificial intelligence (AI), the internet of things (IoT), robotics, Big Data processing, and so on, with traditional industries such as agriculture and manufacturing. In Japan, this type of new society is called Society 5.0. Society 5.0 refers to a concept that the Japanese government aims to achieve, which represents a new type of society (Cabinet Office, 2016). Society 1.0 represents the hunting society, 2.0 represents the agricultural society, 3.0 represents the industrial society, and 4.0 represents the information society. Society 5.0 envisions a society where Society 1.0 to 3.0 are highly integrated with Society 4.0, aiming for sustainable development and the resolution of social challenges. In order to actualize Society 5.0, it is important to connect and integrate cyber technologies and physical technologies. This requires a highly integrated approach between these new technologies and existing industries. These changes in society have necessitated a reform of education. In response to these changes, JSTE has undertaken a revision of "Technology Education in the 21st Century" and has developed "The New Framework of Technology and Engineering Education for Creating a Next Generation Learning" [translated from Japanese] (JSTE, 2021).

In this paper, we report the details of this project. Then, we discuss the research question: What happens when academic society is involved in the design of the technology education curriculum?

Current Status of Technology Education in Japan

First, we introduce the current status of technology education in Japan, which was revised in the 2017 national curriculum (MEXT, 2017). Technology education, as general education in Japan, is positioned within the subject 'Technology' as part of the subject area of 'Technology and Home Economics' in the junior high school curriculum. In the elementary school curriculum, some learning activities include hands-on activities for making things and computer programming activities in various subject areas. However, these activities are not systematized as technology education. In high school, there is a subject called 'Informatics', but there are no other subjects that specifically deal with other areas of technology. Here, let's focus on the junior high school subject 'Technology'. The number of lessons of 'Technology' allocated for each grade level is 35 lessons per year (1 class is 50 minutes) in 7th grade (13 years old), 35 lessons per year in 8th grade (14 years old), and 17.5 lessons per year in 9th grade (15 years old). In the revised national curriculum of 2017, the objectives of 'Technology' are as follows. Also, the learning contents of 'Technology' can be summarized as shown in Table 1 (note: this summary is edited by the authors).

Objectives

Fostering abilities that contribute to the creation of a better life and sustainable society through practical and experiential activities related to technology, utilizing a viewpoint and way of thinking of technology.

(i) To develop a foundational understanding of material processing, biological cultivation, energy conversion, and information technologies that are used in daily life and society; to acquire skills related to these technologies; and to gain a deeper understanding of the relationship between technologies, daily life, society, and the environment.

(ii) To develop technological problem-solving abilities, such as identifying problems related to technology within daily life and society, setting one's own tasks, finding solutions, expressing ideas through drawing or other forms, producing (or cultivating), and evaluating and improving.

(iii) To cultivate practical attitudes for the proper and honest pursuit of technological devices and innovations to realize a better life and build a sustainable society.

The goal of learning in 'Technology' is for students to acquire the ability to evaluate, select, manage, operate, improve, and apply technology, fostering their creativity and problem-solving skills. Among these, the "ability to evaluate, select, manage, and operate technology" refers to the ability of technological governance, which is the multidimensional evaluation of the benefits and risks of technology in society and the democratic control of technological development for the future. Also, the "ability to improve and apply technology" represents the ability of technological innovation, which means the creation of new value in society by using technology. In this curriculum, especially, the construction of four learning contents and the concept of abilities for technological innovation and governance were influenced by JSTE's "Technology Education for the 21st Century" (2012).

In order to develop a new framework for technology and engineering education, we decided to understand how students are learning in the current national curriculum described above, and to examine the direction in which a new framework should go.

Table 1. Overview of Learning Contents of 'Technology' in Japan (Revised in 2017)

		Content A Material and Processing Technology	Content B Biological Technology	Content C Energy Conversion Technology	Content D Information Technology
1	(1)	Understanding the principles and mechanisms of technologies that supporting our daily life and society			
	(2)	Reading ingenuity of technological problem-solving that embedded in existing products or systems.			
2	(1)	Skills for fabrication, production, and cultivation.			
	(2)	Identifying problems, setting tasks, designing solutions and executing technnological problem-solving.			
3	(1)	Understanding the concepts of technology and the role of it in development of society.			
	(2)	Thinking of Evaluating, selecting, managing, operating, improving, and applying technology, and cultivating creative attitude for actualization of sustainable development of society.			

Note: In Content D, section 2(1)(2) in other contents are divided into 2(1)(2)"problem solving by programming with network technology" and 3(1)(2) "problem solving by programming with sensing and control technology". Therefore, 3(1) (2) in other contents is become 4(1)(2) in Content D.

Survey on actual status of students' awareness for learning 'Technology' in Japan

Purpose

We conducted a survey to understand Japanese junior high school students' awareness and learning situations in 'Technology' classes implemented under the current national curriculum.

Method

Subjects

The subjects were 1,656 7th to 9th grade students in Hyogo Prefecture, Japan.

Question Items

The questionnaire consisted of four categories to assess their awareness and experiences regarding 'Technology' classes. The concept of the items is as follows. See the Appendix for specific question items.

1.Awareness towards 'Technology' learning

- 1-1 Importance of learning technology
- 1-2 Joy of learning technology

1-3 Understanding of technology learning
1-4 Interest in technologies that support our daily life and society

Four-point scale: 4: very much, 3: a lot, 2: not much, 1: not at all
Each response being scored from 4 to 1.

2.Status of learning activities related to problem-solving
2-1 Active attitude towards learning in technology classes
2-2 Collaborative learning in technology classes
2-3 Linking own learning experiences with social issues

Four-point scale: 4: very much, 3: a lot, 2: not much, 1: not at all
Each response being scored from 4 to 1.

3. Status of students' problem-solving experiences
3-1 Exploring (inquiry, experimentation, and observation)
3-2 Planning and designing
3-3 Project management
3-4 Troubleshooting

Four-point scale: 4: very much, 3: a lot, 2: not much, 1: not at all
Each response being scored from 4 to 1.

4. Abilities acquired through learning
4-1 Abilities for technological governance
4-2 Abilities for technological innovation

Four-point scale: 4: Very much, 3: Fairly much, 2: Not much, 1: Not at all
Each response being scored from 4 to 1.

Data Analysis

For Items 1, 2, and 3, the mean score and standard deviation (SD) were calculated to determine the actual condition of the students' learning and awareness. After that, multiple regression analysis was conducted with Item 4 as the objective variable and Items 2 and 3 as explanatory variables. A path diagram (Figure 1) was drawn using significant standard partial regression coefficients obtained from the multiple regression analysis.

Result and Discussion

First, students' awareness towards 'Technology' learning is shown in Table 2, which indicates that they have a positive awareness of the importance of 'Technology' classes and perceive them as enjoyable and understandable.

Also, it is suggested that students have an interest in technologies that support our daily lives and society. The status of learning activities related to problem-solving is shown in Table 3. It is suggested that students are actively engaged in self-directed and interactive learning in 'Technology' classes. However, there is a slight weakness in awareness of linking their learning experiences to social issues.

The status of students' problem-solving experiences is shown in Table 4. From Table 4, it was indicated that students are engaged in problem-solving activities such as project management, planning and design, and troubleshooting in 'Technology' classes. However, it was found that students are not sufficiently engaged in exploratory activities such as inquiry, experimentation, and observation related to technology.

Table 2. Students' awareness towards 'Technology' learning.

Items	*Mean*	*SD*	*95%CI*	
			Lower	Upper
Importance of learning technology.	3,24	0,70	3,21	3,27
Joy of learning technology	3,35	0,66	3,32	3,38
Understanding of technology learning	3,08	0,71	3,05	3,11
Interest in technologies that support our daily life and society	3,05	0,69	3,02	3,08

N = 1656
4-point scale

Table 3. Status of learning activities related problem-solving.

Items	*Mean*	*SD*	*95%CI*	
			Lower	Upper
Active attitude for learning in technology classes	3,12	0,70	3,09	3,15
Collaborative learning in technology classes	3,25	0,72	3,22	3,29
To link own learning experiences with social issues	2,34	1,49	2,27	2,41

N = 1656
4-point scale

Table 4. Status of students' problem-solving experiences.

Items	*Mean*	*SD*	*95%CI*	
			Lower	Upper
Exploring(inquiry, experimentation, and observation)	2,64	0,89	2,60	2,68
Planning and designing	3,18	1,34	3,12	3,25
Project management	3,22	0,67	3,19	3,25
Troubleshooting	3,18	1,34	3,12	3,25

N = 1656
4-point scale

A multiple regression analysis was conducted to examine the impact of these learning activities on students' abilities for technological innovation and governance (Figure 1). Incidentally, multiple regression analysis is a statistical method used to investigate how multiple independent variables (predictors) collectively influence a single dependent variable (outcome).

By using multiple regression analysis, we can quantify and assess the causal relationships between several predictor variables and a target variable. As a result, unfortunately, overall, the influences of learning activities on the abilities for technological innovation and governance were weak. Also, the results suggest that problem-solving activities related to planning and design, as well as troubleshooting, are not contributing to the development of the students' abilities. It is considered that this is due to the limited design activities, which may be restricted to activities such as selecting and improving models prepared by the teacher.

Based on these results, the following points can be noted regarding the actual status of students in 'Technology' classes in Japan. Japanese students have a positive perception of 'Technology' classes; however, there is a lack of sufficient learning activities that involve exploring technology. Additionally, the most important element of technology education, which is design problem-solving, is not adequately linked to the development of abilities for technological innovation and governance. From this point of view, it is believed that the future of technology education in Japan should focus on enhancing exploratory activities and problem-solving related to engineering. Considering the role of STEM/STEAM education moving forward, it is necessary to prioritize design learning as the core and foster abilities for technological innovation and governance.

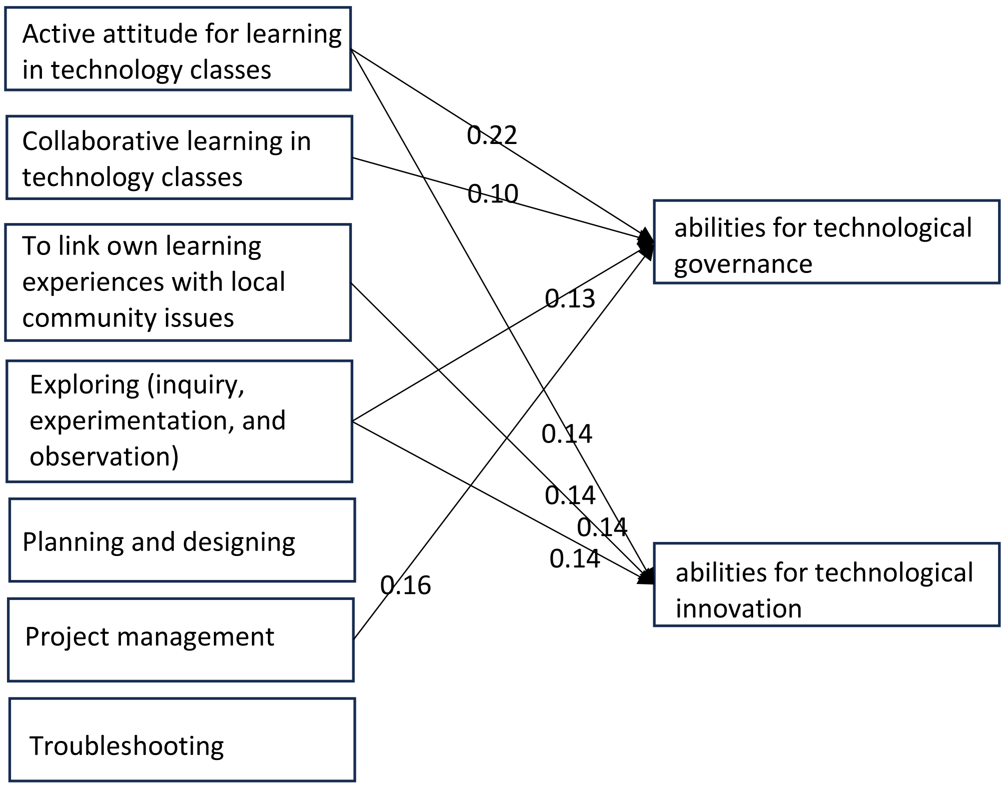

Figure 1. Causal relationship toward students' abilities for technological innovation and governance.

Development of New Framework for Technology and Engineering Education

In light of this, JSTE initiated a project to revise the "Technology Education in the 21st Century" curriculum in 2017. As part of JSTE's initiatives, we first established a 'Technology Education Ideathon' session. 'Ideathon' is a term coined by combining 'idea' and 'marathon', which refers to a creative discussion platform where participants continuously generate various ideas. JSTE has been organizing ‘Ideathon’ on an annual basis since 2017. Additionally, the project has held four symposiums during JSTE’s annual conferences from 2019 to 2022, in order to gather various opinions from JSTE’s members. In this process, the name of ‘Technology Education’ was changed to ‘Technology and Engineering Education’. Then, the project reached the milestone of publishing “The New Framework for Technology and Engineering Education to Create the Next Generation of Learning” (NGTE) in 2021.

Objective of Technology and Engineering Education in NGTE

NGTE divides technology and engineering education into two categories for discussion: professional education for cultivating technological experts such as engineers, technologists, etc., and general education for fostering technology and engineering literacy among all citizens. Particularly, NGTE focuses on technology and engineering literacy education. NGTE defines acquiring the abilities for technological innovation and governance as the final goal of technology and engineering literacy. An overview of the objectives to achieve this goal is summarized in Table 5.

In Table 5, technology and engineering literacy is positioned on the left side. It shows how this literacy enhances generic competences. It shows that technology and engineering literacy plays an important role not only in developing abilities related to technology and engineering but also in developing generic competences at three layers: as “individual,” “engaging with others,” and “life and social development.” The envisioned future shape of students who have learned technology and engineering education are “A: Technologically literate citizens,” “B: Responsible users of technology,” “C: Creative individuals as technological problem-solvers,” “Lifelong learners about technology,” “Decision-makers related to technology,” “Eggs of engineers,” and “Promoters of culture to actively support technological development in society.” These images represent the desired outcomes for students in technology and engineering education.

Table 5. Overview of Objectives of Technology and Engineering Education in NGTE

Technology and Engineering Literacy	**Competencies enhanced by technology and engineering literacy**		
	As individual	Engaging with others	Life and social development
Scientific understandings of technology and engineering Understandings of interconnection between technology and society, environment, economy and so on.	Integrative recognition and application abilities in both STEM and Arts	logical communication (expression, share, argument)	Career development and self-actualization
Development of abilities to technological problem-solving and engineering.	design thinking critical thinking logical thinking computational thinking system thinking GRIT etc	cooperative skills collaborative skills menbership leadership followership etc	Abilities to move various projects forward in lifelong
Development of abilities to participate in technological governance in society.	Jadgment abilities Decision making abilities Fairness Citizenship etc	Abilities to engage in democratic and constructive dialogue	
Development of abilities to participate in technological innovation in society.	Creativity Proposal skills etc	Open mind Reciprocal relations etc	Abilities for building democratic and sustainable societies

Scope of Technology and Engineering Education in NGTE

NGTE has strengthened the following two points, considering the content structure of Japan's previous technology education. First, NGTE incorporated elements of engineering science in order to emphasize problem-solving through the exploration of technology by establishing the relevance between each content and its underlying academic discipline. Secondly, NGTE has enhanced the connections between technology and other diverse areas of expertise to enable students to create new value in a VUCA (Volatile, Uncertain, Complex, Ambiguous) society. This has been incorporated into the learning content as 'Technological Systems', emphasizing the interplay between technology and various other domains in society. Especially, we addressed the integration of cyber technologies and physical technologies based on the concept of Society 5.0. We believe these contents are linked to the abilities for technological innovation and governance. The proposed scope of technology and engineering education in NGTE is shown in Figure 2.

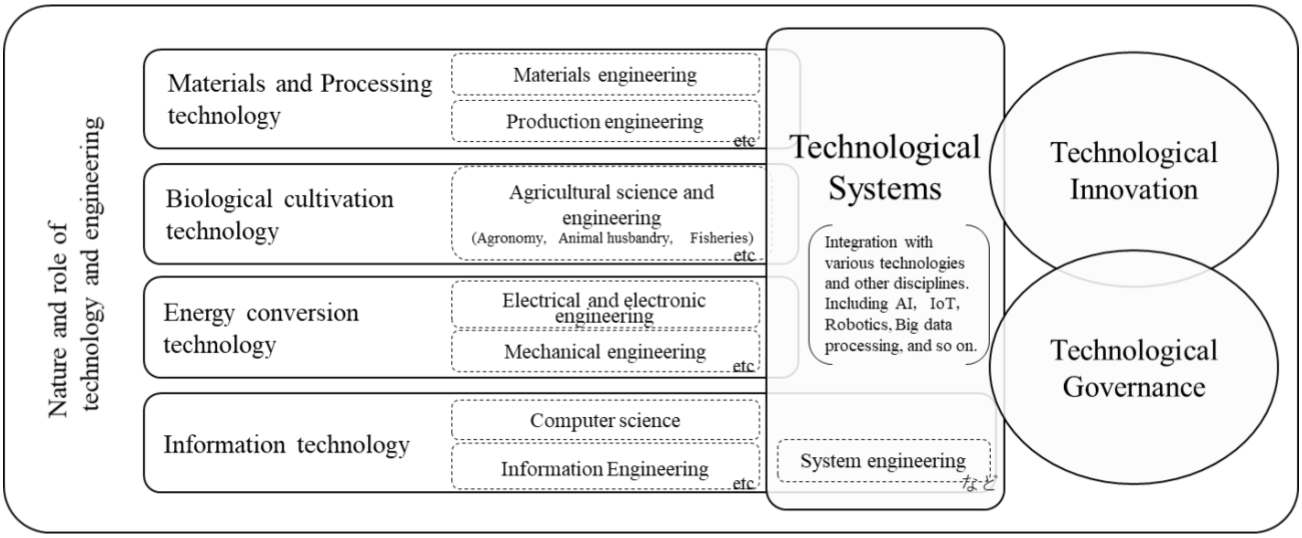

Figure 2. Scope of Technology and Engineering Education in NGTE.

In Figure 2, "understanding of the nature and roles of technology" is positioned to cover the whole scope. On top of that, individual technologies such as "materials and processing technology," "energy conversion technology," "biological cultivation technology," and "information technology" are positioned. Within this structure, engineering sciences, which are the background disciplines for each technology, such as materials engineering, electrical and electronic engineering, agricultural science, computer science, and so on, are positioned. Furthermore, as content that spans individual technologies, 'Technological Systems' is positioned. This content includes AI, IoT, robotics, Big Data processing, and more, aiming to integrate cyber and physical technologies. We aim to connect this learning to technological innovation and governance in order to foster the ability to create new value through technology and enable democratic steering in the direction of technology development.

Triple-loop model of Engineering Design Process in NGTE

As the results of the above survey have shown, there were issues regarding Japanese students not having sufficient learning experiences to explore the principles and mechanisms of technologies, and they could not apply the design process to their technological innovation and governance. To address these issues, we proposed the Triple Loop Model of the Engineering Design Process (Figure 3). Note: in the diagram below, 'PDCA' stands for Plan, Do, Check, Action, and 'STPD' stands for See, Think, Plan, Do, referring to different management cycles.

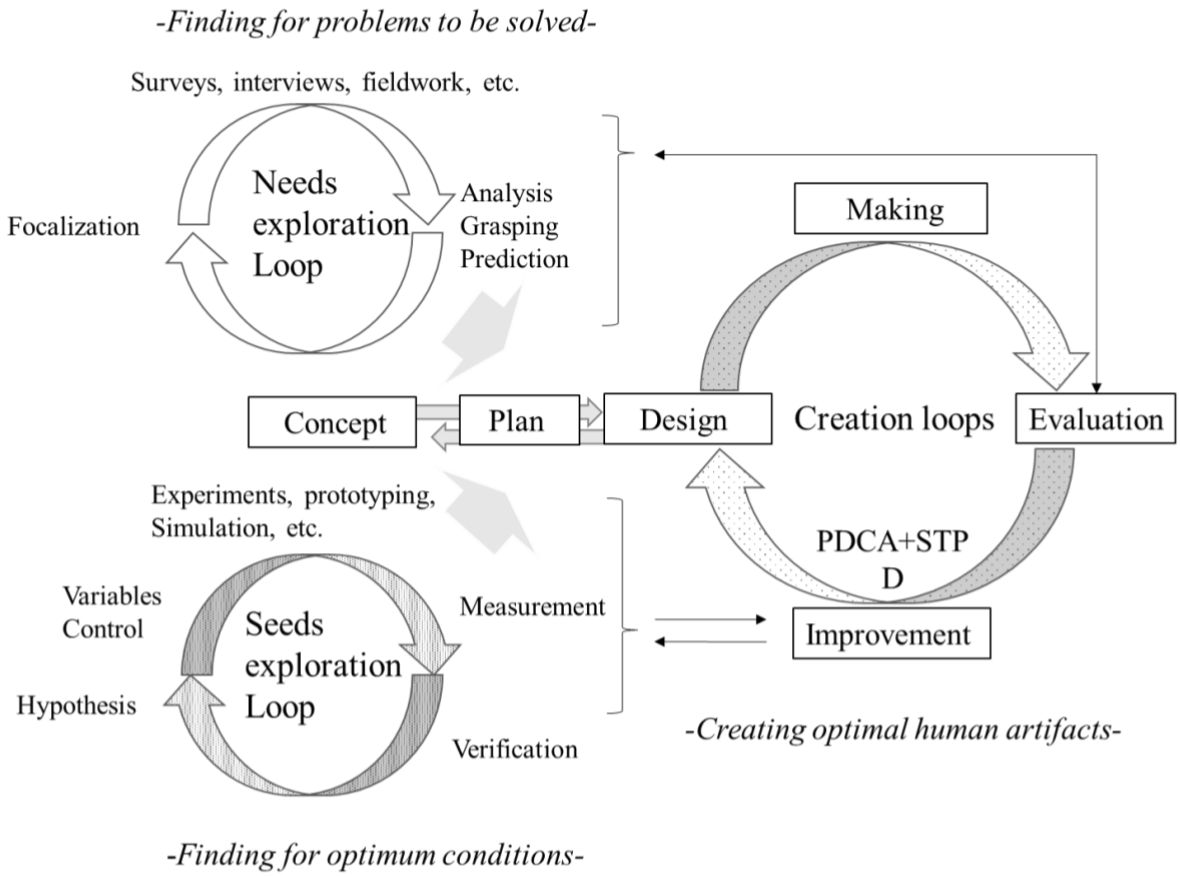

Figure 3. The Triple Loop Model of engineering design process in NGTE.

The Triple Loop Model illustrated an engineering design process that is constructed from iterative interaction of three loops such as Needs Exploration Loop, Seeds Exploration Loop, and Creation Loop. In the Needs Exploration Loop, students will utilise various methods such as surveys, interviews, or fieldwork and analyse various materials and data in order to identify problems, set tasks, and clarify users' needs. In the Seeds Exploration Loop, students set variables and explore optimal conditions for technological problem-solving. Furthermore, students engage in activities such as prototyping and simulations to devise optimal designs. In the Creation Loop, students match both 'needs' and 'seeds', and they design what should be created by optimisation thinking and make appropriate products or systems.

A Learning Model of STEAM Education in NGTE

Finally, the Learning Model of STEAM education that centred on the engineering design process in NGTE is shown in Figure 4.

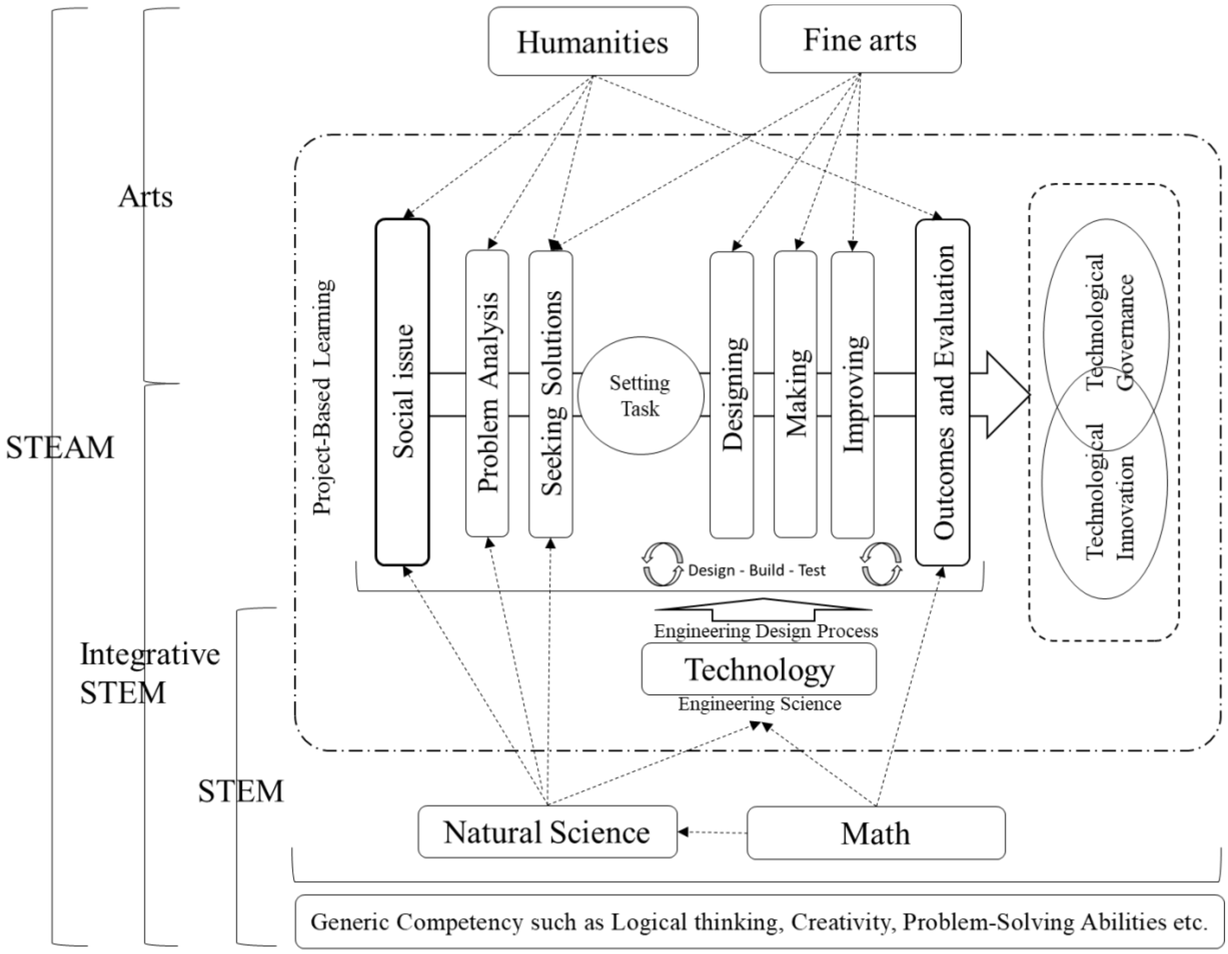

Figure 4. Learning Model of STEAM education that centred engineering design process in NGTE.

Essentially, technology and engineering play an important role in bridging the gap between natural science and society/culture through the design process. Therefore, in the context of STEAM education, technology and engineering literacy play an important role in connecting the disciplines of science, arts, and mathematics. It serves as a link that integrates these disciplines and makes STEAM education practices more holistic and comprehensive. In general, in STEAM education with project-based learning, there are opportunities for students to create both technological artefacts and non-technological outcomes. In NGTE, we focused on the former, and have envisioned a practical model of STEAM education that centred on engineering-based problem-solving through transdisciplinary learning across all subjects. This learning model is summarized in Figure 4. The model specifically focuses on setting up learning activities for creating technological artefacts such as useful products or systems that may be able to solve authentic problems in our society. Of course, there are various models of STEAM education. This is an example of one that can be implemented in ‘Technology’ classes or ‘Period of Integrated Study’ in Japan’s national curriculum.

Evaluation of NGTE

To evaluate the developed NGTE (draft version), a symposium was held with JSTE members, and a survey was conducted for evaluation. Responses were scored on a 4-point scale from "very much agree" to "do not agree at all" for each proposal, with each response being scored from 4 to 1. The neutral point between agreement and disagreement was 2.50. Here, the high mean value indicates the degree of agreement, and the SD indicates the degree of scattering of opinions (Table 6). Most of the proposals had a mean value of 3.00 or higher, indicating that the participants agreed with the proposals. However, the expression of the concept of the term "engineering" (2.78) had a mean value of less than 3.00 and a larger SD than the others.

The expression of the concept of the term 'Engineering' in the draft version was: "Engineering is the scientific process of creating (producing, developing, inventing) optimal artefact systems to realise human needs, and the knowledge systems (disciplines) involved in realising this process."

Table 6. Result of Evaluation on NGTE.

Items	*Mean*	*SD*	*95%CI*	
			Lower	Upper
Concept of Technology and Engineering Literacy in NGTE	3,27	0,76	3,11	3,43
Concept of the term "Technology" in NGTE	3,20	0,81	3,03	3,37
Concept of the term "Engineering" in NGTE	2,78	0,97	2,58	2,98
Objectives of Technology and Engineering Education in NGTE	3,24	0,71	3,09	3,39
Scope of Technology and Engineering Education in NGTE	3,30	0,66	3,16	3,44
Triple-loop model of Engineering Design Process in NGTE	3,23	0,74	3,08	3,38
A Learning Model of STEAM Education in NGTE	3,01	0,80	2,85	3,18

N = 90
4 point scale

We considered the expression of this term in the draft version was not sufficient as an explanation of this complex word. Therefore, we decided to change this expression in the final version of NGTE. The revised expression is as follows:

> *Engineering is a scientific problem-solving strategy for creating (production, development, and invention) optimal human-made products to realise human needs, and the knowledge systems related to the realisation of these problem-solving strategies. The knowledge system in engineering is the science related to technology,*

which can be referred to as engineering science. On the other hand, the design process is the process of applying a systematic problem-solving strategy to select a final idea from among several possible solutions, while clarifying evaluation criteria and constraints, to satisfy human needs by applying design thinking. The design process to optimise technology using the knowledge in engineering science can be called the engineering design process.

Using this expression, we provided a comprehensive description of this complex concept by incorporating both engineering science and the engineering design process.

Discussion

In this paper, we reported how the JSTE developed the new framework for technology and engineering education in Japan. As a result, we showed the current status of Japanese students, indicating that they have a positive perception of 'Technology' classes; however, there is a lack of sufficient learning activities involving the exploration of technology, and design problem-solving is not adequately linked to the abilities for technological innovation and governance. In light of these issues in students' learning and changes in society, we developed a new framework that focused on enhancing exploratory activities and problem-solving related to engineering. The proposal included the Triple-Loop Model as the engineering design process, the connections between physical and cyber technologies in that scope, and the learning model of STEAM education that centred on the engineering design process with various connections among all subject areas.

Zuga (1989) points out that there are five categories in curriculum design and development in technology education: (a) technical performance or processes; (b) academic focus on the specific body of knowledge relating to industry and technology; (c) intellectual processes that concentrate on critical thinking and problem solving; (d) social reconstruction through realistic or real-world situations; and (e) personal, learner-centred focus on individual needs and interests. Applying these categories to the NGTE, the engineering design process based on the Triple-Loop Model (Figure 3) covers (c) intellectual processes that concentrate on critical thinking and problem solving, (a) technical performance or processes, and (e) personal, learner-centred focus on individual needs and interests. The Triple-Loop Model itself is a direct element of (c) intellectual processes in engineering activities. Setting topics according to students' interests and concerns in projects using this model leads to (e) personal, learner-centred focus. Additionally, creating prototypes in projects relates to (a) technical performance or processes. Also, the scope structure that connects physical and cyber technologies in the NGTE, and the STEAM education model centred on engineering activities, are linked to societal changes in Japan aimed at realising Society 5.0. Therefore, they cover (d) social reconstruction through realistic or real-world situations. Additionally, this scope is related to (b) academic focus on the specific body of knowledge relating to industry and technology, as it describes the connection with engineering science within each content area in Figure 2. The NGTE thus aligns well with the five categories involved in curriculum development in technology education proposed by Zuga.

Here, the significance of this study is discussed from a meta-perspective. It concerns the role of researchers and academic societies in the revision of the national curriculum. The process presented in this paper can be organised as follows. The first step is to ascertain the current situation of learners who have studied in the current national curriculum. The second step is to interpret the current situation of these learners in relation to the direction of curriculum revision linked to social changes. The third step is to conceive and concretize the proposed curriculum revision to bridge the gap between the current situation of these learners and the competencies required by the next generation.

Currently, this is the third step, but a fourth step, involving the concrete revision of the national curriculum, is forthcoming. In the first step, academic insights are needed to determine the content and methodology of the survey and analyse it scientifically. This is an issue that academic societies should address. In the second step, the MEXT will set the direction for a major revision of the national curriculum, based on national policy and societal changes. It is important to interpret the gap between this direction and the actual situation of the identified learners. In the third step, the academic society will develop a curriculum standard to serve as a reference for the revision of the national curriculum, which will occur in the fourth step. This is the NGTE presented in this paper. The fourth step, as mentioned in the introduction, will be carried out by the Council of the MEXT. It is believed that the participation of academic societies here will enable the concept of curriculum standards developed in the third step to be reflected, to a certain extent, in the revision of the national curriculum.

In this study, the first and third steps were undertaken by academic societies (JSTE), and Senior Specialist for Curriculum from the MEXT were involved in the project. The second step is a more senior decision-making process within the MEXT, so it is not easy for members of academic societies to participate in the project at present. However, in the fourth step, members of academic societies are expected to participate in working groups for revising technology education curriculum. This scheme of collaboration between administrative bodies and academic societies to revise the national curriculum is considered to be particularly important in the development of technology education curriculum, which are susceptible to updates in learning content and changes in the required competencies.

Future tasks

We intend to use the NGTE to challenge the next educational reform in Japan. We would like to report on the process of this in a future. However, the Scope of Technology and Engineering Education, Triple-Loop Model and STEAM Learning Model are still hypothetical at this stage. It will be necessary to make clear the effects of these strategies through classroom practice. Wicklein (1997) states that there is a gap between what technology education curricula aim to teach and what is actually practised in classrooms. According to him, while educators advocate for teaching critical thinking and problem-solving, classrooms often use rigid models and focus heavily on technical skills. Despite the emphasis on understanding technology’s societal and environmental impacts, this aspect is often neglected in favour of specific skill development. In our project, we proposed The NGTE as a new framework for technology education. However, to effectively implement practices based on this curriculum, it is essential to reform teacher education and training. This will be the fifth step. We plan to address these challenges moving forward.

Notes

This article is based on a conference paper presented at the PATT40 Liverpool 2023 conference and is aligned with Strand 2: exploring and advancing teaching and learning for design and technology education (Moriyama et al., 2023).

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Appendix

Specific question items

1. Awareness towards 'Technology' learning
   1-1 Do you think learning in technology classes is important?
   1-2 Is learning in technology classes fun?
   1-3 Can you understand the learning content in technology classes?
   1-4 Are you interested in the technology that supports daily life and society?

2. Status of learning activities related to problem-solving
   2-1 Do you have an active attitude in technology classes?
   2-2 Are you learning collaboratively in technology classes?
   2-3 Are you linking your learning experiences in technology classes to issues in daily life and society?

3. Status of students' problem-solving experiences
   To what extent have you engaged in the following problem-solving experiences in technology classes?
   3-1 Exploring (inquiry, experimentation, and observation)
   3-2 Planning and designing
   3-3 Project management
   3-4 Troubleshooting

4. Abilities acquired through learning
   4-1 Do you think you have acquired abilities for technological governance through learning in technology classes?
   4-2 Do you think you have acquired abilities for technological innovation through learning in technology classes?

Student Insights on Product Improvement and User Perspectives in Japanese Junior High Technology Education

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Abstract
This study investigates junior high school students' perspectives on improving manufactured products and their perceptions as users after participating in materials processing technology learning in Japan. Guided by recent changes in Japanese curriculum guidelines emphasizing real-world application, we conducted a web-based survey collecting 721 valid responses from 833 students. The survey explored students' enjoyment of and satisfaction with materials processing learning, as well as their intentions regarding future technology-related careers. Our findings reveal high engagement in practical tasks, with 91.7% of students expressing positive attitudes towards making things. However, only 41.5% viewed their experiences as positively impacting future career aspirations. When prompted to describe product improvements, students frequently focused on safety (45.2%) and functionality (34.4%), while often neglecting environmental and economic factors. Differences emerged between those who described user-oriented improvements and those who did not, suggesting that descriptive reflection may enhance safety awareness and other practical concerns. This study contributes to the ongoing discourse on technology education by highlighting the need for curricular advancements that better link technological learning with future career opportunities. It also underscores the importance of fostering a comprehensive design approach that includes societal and environmental considerations.

Keywords
Technology Education, Design and Making things, User perspectives, Viewpoints on the Improvement of Products

Introduction
Technology education plays a crucial role in preparing students for the challenges of an increasingly technological world. In Japan, recent curriculum changes have sought to align classroom learning more closely with real-world technical challenges, reflecting a global trend towards more practical and applied technology education (Ritz & Fan, 2015). This study aims to explore junior high school students' perspectives on improving manufactured products and their perceptions as users after participating in materials processing technology learning.

The significance of this study lies in its integration of theoretical knowledge with practical applications, which is vital for students to understand and influence technology's evolving role in society. As Williams (2009) argues, technological literacy is a key component of modern democracy, requiring a broader and more inclusive approach to technology education. In Japan, this shift is reflected in the Ministry of Education, Culture, Sports, Science, and Technology's curriculum guidelines, which emphasize reflective, critical, and innovative education in technology (Ministry of Education, Culture, Sports, Science, and Technology, 2017a; 2017b).

Internationally, there has been a growing emphasis on integrating engineering and technology more comprehensively into broader curricula. For example, the Next Generation Science Standards (NGSS) in the United States encourage an interdisciplinary approach, blending engineering practices with core scientific concepts to address real-world problems (NGSS, 2013). Similarly, the European Commission's educational directives emphasize incorporating sustainability and societal needs within the framework of technology education (European Commission, 2020). Ritz and Fan's (2015) comprehensive review of STEM and technology education across different countries highlights the global trend towards integrating these fields. They note that while approaches vary, there is a common thread of emphasizing practical, hands-on learning experiences that connect classroom knowledge to real-world applications.

Despite these robust frameworks, significant challenges persist in effectively applying and integrating these educational goals. Matsuda (2006) highlights the linguistic and cultural complexities in interpreting technology education in Japan, pointing to the need for careful consideration of how concepts are translated and applied in practice. This echoes broader concerns raised by Dakers (2006), who argues for a more nuanced understanding of technological literacy that goes beyond mere technical skills. Barak (2018) discusses the evolution of electronics education, emphasizing the importance of system thinking and programming in modern technology education. This shift towards more complex, integrated approaches to technology presents challenges for both educators and students, particularly in terms of curriculum design and implementation.

Understanding student attitudes and perceptions is crucial for effective technology education. Ardies et al. (2013) developed and validated a survey instrument for measuring students' attitudes towards technology, highlighting the importance of this aspect in educational research. Building on this, Ankiewicz (2019) calls for more rigorous theoretical frameworks in attitude research, emphasizing the need for a deeper understanding of how students perceive and engage with technology. Svenningsson et al. (2018) critically examined the widely used Pupils' Attitudes Towards Technology (PATT) questionnaire, discussing the complexities of interpreting and using attitude measurements in technology education research. Their work underscores the importance of robust methodological approaches in studying student perceptions.

Project-based learning has emerged as a key approach in technology education. Fox-Turnbull (2016) analysed student conversations during technology education activities, providing insights into the development of technological thinking in primary education. This work highlights the importance of hands-on, collaborative learning experiences in fostering technological understanding. Rauscher (2011) examined the types of technological knowledge applied by students in practical tasks, emphasizing the importance of aligning curriculum design and assessment with real-world problem-solving. This aligns with the growing emphasis on user-centered design in technology education, as discussed by Khunyakari et al. (2009) in their work on design-based curricula for diverse student populations.

The role of teachers in implementing effective technology education cannot be overstated. Chikasanda et al. (2013) proposed a professional development model for technology teachers, emphasizing the need to enhance technological pedagogical knowledge and practices. This is particularly relevant in the context of rapidly evolving technological landscapes and educational paradigms. Martin (2017) analysed policy documents related to primary technology education in England, discussing the challenges of preparing teachers for technology education. This work highlights the importance of aligning teacher education with the evolving goals and methods of technology education.

De Vries (2016) provides a comprehensive overview of the philosophy of technology for educators, emphasizing the importance of philosophical understanding in technology education. This work contributes to a deeper, more nuanced approach to teaching technology that goes beyond mere technical skills. Hallström and Gyberg (2011) argue for the importance of including the history of technology in education, suggesting ways to integrate historical perspectives into technology curricula. This historical context can provide students with a richer understanding of technological development and its societal impacts.

Buckley et al. (2019) explored the use of spatial reasoning strategies in geometric problem solving, highlighting the importance of developing these skills in technology education. Their work suggests that spatial reasoning abilities play a crucial role in students' capacity to engage with complex technological problems.

Comparative studies provide valuable insights into different approaches to technology education. Autio and Soobik (2017) compared technology education in Finland and Estonia, analysing students' technological knowledge and reasoning skills. Such studies highlight both commonalities and differences in educational approaches across different cultural contexts. Koski and de Vries (2013) investigated young students' understanding of technological systems, providing implications for curriculum design in primary technology education. Their work emphasizes the importance of developing systemic thinking skills from an early age.

In Japan, the introduction of the 'triple-loop model' by the Japan Society of Technology Education in 2022 represents a substantial advancement toward aligning classroom problem-solving activities with real-world technical challenges (Japan Society of Technology Education, 2022). This model, which includes the 'Social scientific needs exploration loop,' 'Experimental science seeds exploration loop,' and 'Creation of optimal deliverables loop,' fosters a dynamic, iterative learning process (figure 1).

While previous research has examined technology education in various contexts, there is a lack of studies focusing specifically on how different production methods in materials processing learning influence Japanese junior high school students' perceptions of user needs and product improvements. This study aims to fill this gap by exploring the viewpoints of improvement and user perceptions that students develop through materials processing learning. We focus on the initial experiences of junior high school students, conducting post-study surveys to assess how different production subjects influence their understanding of user needs and product improvements.

The research questions guiding this study are:

1. How do junior high school students perceive user needs and product improvements after engaging in materials processing learning?
2. What impact do different project types (free design, choice kit, unified kit) have on students' understanding of user-centered design principles?
3. How do students' experiences in materials processing learning relate to their attitudes towards technology and future career considerations?

By addressing these questions, this study aims to contribute to the ongoing discourse on technology education reform, providing empirical evidence to inform curriculum design and teaching practices in Japan and beyond.

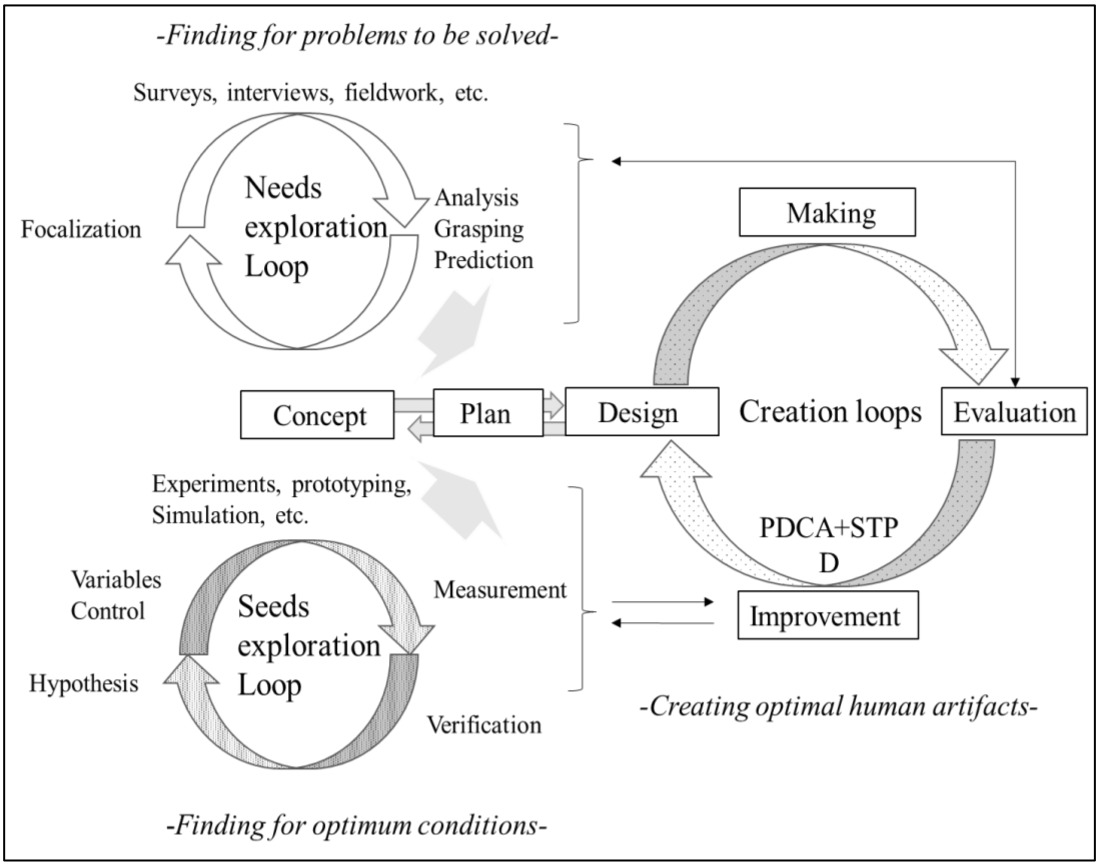

Figure 1: The triple-loop model of the technical problem-finding and solving process, The Japan Society of Technology Education (2022).

Survey Method

Justification for Survey Approach

This study employed a survey method to collect data on students' perspectives and attitudes towards materials processing learning. A survey approach was chosen for several reasons:

1. Breadth of data collection: Surveys allow for gathering information from a large number of participants efficiently, providing a broad overview of student experiences and attitudes (Creswell & Creswell, 2018).

2. Standardization: The use of a structured questionnaire ensures that all participants respond to the same set of questions, facilitating comparisons across different groups and production types (Fowler, 2013).
3. Quantifiability: Survey data can be easily quantified and analysed statistically, allowing for the identification of patterns and trends in student responses (de Vaus, 2013).
4. Compatibility with previous research: Many studies in technology education have used survey methods (e.g., Ardies et al., 2013; Svenningsson et al., 2018), allowing for potential comparisons with existing literature.

Participants and Sampling

The study involved 833 junior high school students (8th-9th grade) in Japan. After excluding incomplete or irregular responses, 721 valid responses were obtained (valid response rate: 86.6%). Participants were recruited from multiple schools to ensure a diverse sample and enhance the generalizability of findings.

Table 1. Surveyed production and number of subjects.

Type of production subject	Description	Target
free production	Free to design and produce own products. There are limitations on the size of materials used (e.g., laminated pine wood, L1800mm, W300mm, H15mm).	4 junior high schools, 366 students
choice kit	Choose from about ten different designs to fabricate. For example, choose from magazine racks, tissue boxes, accessory boxes, etc. There are limitations on the size of materials used (e.g., laminated pine wood, L1200mm, W150mm, H15mm).	2 junior high schools, 253 students
unified kit	Produce a designed book stand. The wood is vertically laid and requires little fabrication time. The size of the material is only just large enough to fabricate.	one junior high school, 102 students

Types of Production Subjects

To address the reviewers' concerns about clarity, we explicitly define the three types of production subjects involved in this study (Table 1):

1. Free design production (n = 366): Students were allowed to design and produce their own products, with limitations only on the size of materials used (e.g., laminated pine wood, L1800mm, W300mm, H15mm).
2. Choice kit (n = 253): Students chose from approximately ten different pre-designed options (e.g., magazine racks, tissue boxes, accessory boxes) to fabricate. Material limitations were similar to the free design group.
3. Unified kit (n = 102): All students in this group produced a designed book stand. The wood was vertically laid and required minimal fabrication time.

These different production types were included to investigate how varying levels of design freedom and structure might influence students' perceptions and learning outcomes. The free design production allows for maximum creativity, the choice kit offers a balance between guidance and choice, while the unified kit provides a highly structured experience. This range of approaches enables us to examine how different levels of autonomy in the design process affect students' understanding and attitudes.

Survey Instrument

The survey was conducted using a web-based tool (Google Form) to facilitate data collection and reduce data entry errors. The questionnaire consisted of two main parts:

1. Items assessing consciousness and learning experiences in 'material-processing learning':
   "I like making things" ('like making things')
   "I like the technology classes" ('like technology classes')
   "I like to think about concepts and design" ('like concept and design')
   "I am satisfied with my production in technology classes" ('satisfied with my production')
   "I would like to have a career in the future related to what I learned in my technology classes" ('career in the future')

2. These items were rated on a 4-point Likert scale: 4 (strongly agree), 3 (agree), 2 (somewhat disagree), and 1 (strongly disagree). An open-ended question assessing viewpoints and user perceptions of manufactured product improvement:
   "If you were a developer of a material processing product and wanted to improve the product you have made, for whom and in what areas would you improve it? Please describe freely without considering your skill level."

Data Collection Procedure

The survey was administered in April 2022 during regular technology classes by the students' technology teachers. This timing was chosen to capture students' perceptions shortly after completing their materials processing projects. Teachers were provided with standardized instructions to ensure consistent administration across different classrooms and schools.

Data Analysis Methods

To address the reviewers' concerns about the lack of detail on analysis methods, we provide a more comprehensive explanation of our analytical approach:

1. Quantitative Analysis:
   Descriptive statistics (frequencies, means, standard deviations) were calculated for the Likert-scale items.
   One-way analysis of variance (ANOVA) was conducted to compare responses across the three production types, with post-hoc Bonferroni tests for multiple comparisons.
   Chi-square tests were used to analyse the association between production type and categorical variables derived from the open-ended responses.
2. Qualitative Analysis of Open-Ended Responses:
   Responses to the open-ended question were analysed using a thematic content analysis approach (Braun & Clarke, 2006).
   Two researchers independently coded a subset of responses to develop an initial coding framework.
   The entire dataset was then coded using this framework, with regular meetings to resolve any discrepancies and refine the coding scheme.

Codes were grouped into broader themes related to user perception and product improvement.

3. Mixed Methods Integration:
   Results from the quantitative and qualitative analyses were integrated to provide a comprehensive understanding of students' perspectives and experiences. Triangulation of quantitative and qualitative data was used to enhance the validity of findings (Creswell & Plano Clark, 2017).

Ethical Considerations

Ethical approval for this study was obtained from [relevant ethics committee]. Informed consent was obtained from all participants and their parents/guardians. Participants were assured of the confidentiality and anonymity of their responses, and they were informed of their right to withdraw from the study at any time without consequence.

Limitations

We acknowledge several limitations of our survey method:

The cross-sectional nature of the study limits our ability to track changes in student perceptions over time.

The self-report nature of the data may be subject to social desirability bias.

The sample, while large, is limited to specific regions in Japan and may not be fully representative of all Japanese junior high school students.

These limitations will be considered when interpreting and discussing the results of the study.

Table 2. Frequency and rate of items for assessing consciousness and learning experiences toward 'material-processing learning'.

		frequency	rate
like making things	Positive	661	91.7%
	Negative	60	8.3%
like technology classes	Positive	661	92.6%
	Negative	60	7.4%
like concept and design	Positive	549	76.1%
	Negative	172	23.9%
satisfied with my production	Positive	600	83.2%
	Negative	121	16.8%
career in the future	Positive	299	41.5%
	Negative	422	58.5%

Results

Student Attitudes and Experiences

Frequencies of acquired answers in Items for assessing consciousness and learning experiences toward 'material-processing learning' were counted to understand subjects' situations (Table 2). A significant majority expressed a positive attitude toward making things (91.7%) and attending technology classes (92.6%). When it comes to the conceptual aspects of technology, such as concept and design, the positive response rate was 76.1%. Regarding satisfaction with personal production, 83.2% of students reported positive feelings. However, only 41.5% view their experiences in technology classes as positively impacting their future careers.

In addition to the overall trend, the data were tabulated by groups regarding the subject matter produced (Table 3). For 'like making things', the overall mean was 3.34 (SD = 0.64). A one-way analysis of variance by production subject showed a significant main effect of subject matter ($F = 6.82$, $p < .01$). Multiple comparisons using Bonferroni revealed significantly higher means for the Group of unified kit (M = 3.56, SD = 0.54) than for the Group of choice kit (M = 3.30, SD = 0.61) and the Group of free production (M = 3.31, SD = 0.68).

Table 3. Means, Standard Deviations, and One-Way Analyses of Variance in assessing consciousness and learning experiences toward 'material-processing learning'.

		Mean	S.D.	ANOVA	Bonferroni
like making things	all	3.34	0.64		
	unified kit	3.56	0.54		unified kit > choice kit **
	choice kit	3.30	0.61	$F_{(2,718)}$= 6.82 **	unified kit > free production **
	free production	3.31	0.68		choice kit free production *n.s.*
like technology classes	all	3.33	0.64		
	unified kit	3.54	0.54		unified kit > choice kit **
	choice kit	3.37	0.57	$F_{(2,718)}$= 9.49 **	unified kit free production *n.s.*
	free production	3.24	0.70		choice kit > free production *
like concept and design	all	2.97	0.77		
	unified kit	3.24	0.63		unified kit > choice kit **
	choice kit	3.04	0.74	$F_{(2,718)}$= 11.69 **	unified kit free production *n.s.*
	free production	2.85	0.80		choice kit > free production *
satisfied with my production	all	3.10	0.69		
	unified kit	3.27	0.63		unified kit choice kit *n.s.*
	choice kit	3.21	0.63	$F_{(2,718)}$= 12.4 **	unified kit > free production **
	free production	2.98	0.73		choice kit > free production **
career in the future	all	2.39	0.77		
	unified kit	2.53	0.80		
	choice kit	2.39	0.74	$F_{(2,718)}$= 2.02 *n.s.*	
	free production	2.36	0.79		

***p<.01， *p<.05*

The overall mean for 'like technology classes' was 3.33 (SD = 0.64). The main effect of the subject matter was significant ($F = 9.49$, $p < .01$), with significantly higher means in the Group of choice kit (M = 3.37, SD = 0.57) and the Group of unified kit (M = 3.54, SD = 0.54) than in the Group of free production (M = 3.24, SD = 0.70).

For 'like concept and design', the overall mean was 2.97 (SD = 0.77). The main effect of subject matter was significant ($F = 11.69$, $p < .01$), with significantly higher means in the Group of choice kit (M = 3.04, SD = 0.74) and the Group of unified kit (M = 3.24, SD = 0.63) than in the Group of free production (M = 2.85, SD = 0.73).

For 'satisfied with my production', the overall mean was 3.10 (SD = 0.69). The main effect of the subject matter was significant ($F = 12.40$, p < .01), with significantly higher means in the Group of choice kit (M = 3.21, SD = 0.63) and the Group of unified kit (M = 3.27, SD = 0.63) than in the Group of free production (M = 2.98, SD = 0.73).

For 'career in the future', the overall mean was 2.39 (SD = 0.77). No significant differences were found in the main effects of the subject matter (F = 2.02, p = .53).

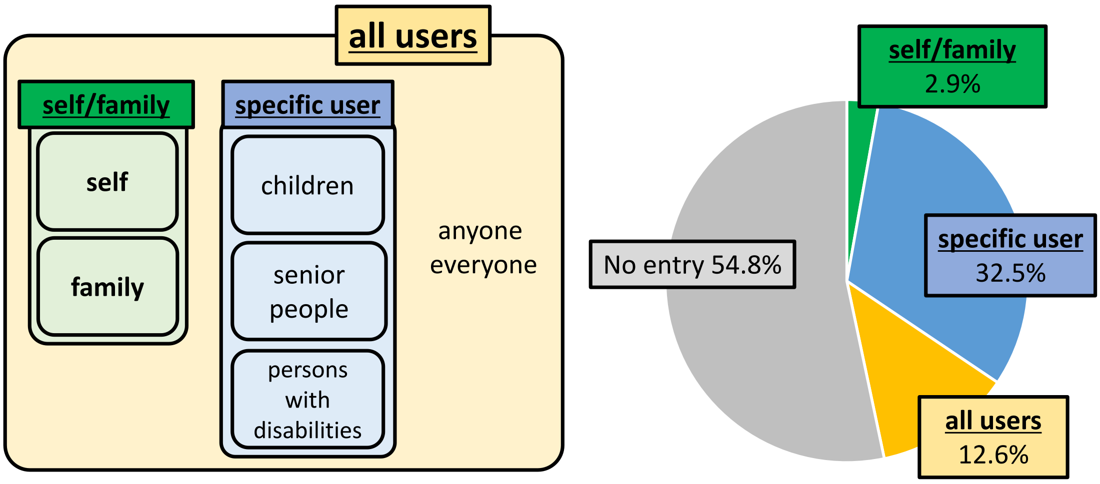

Figure 2. Distribution of User Consideration Categories in Student Projects

User Perception Analysis

When the data were tabulated, 364 descriptions (multiple responses: 326 respondents, 45.2% response rate) regarding user perception were received (Figure 2). Three categories were established from the viewpoint of user perception: 'self/family', 'specific user', and 'all users'.

Table 4 presents the frequency of responses and chi-square results of user perception across the three production types. The analysis indicated that most students (32.5%) considered specific users when completing their projects. This was consistently observed across all modalities: free production (34.7%), choice kit (28.9%), and unified kit (33.3%). When considering all users, the frequency was notably lower at 12.6% overall, with a slight variation across modalities but no significant difference (χ2 = 1.57, ns). The consideration for self or family was minimal across modalities, with the total frequency being 2.9%. Notably, no instances were recorded in the unified kit group, but the difference across groups was not statistically significant.

Table 4. Frequency of responses and chi-square results of user perception

	All (N=721)		free production (n=366)		choice kit (n=253)		unified kit (n=102)		Comparison between groups	
	frequency	rate	frequency	rate	frequency	rate	frequency	rate		
self/family	21	2.9%	14	3.8%	7	2.8%	0	0.0%		*n.s.*
specific users	234	32.5%	127	34.7%	73	28.9%	34	33.3%	$\chi^2_{(2)}$= 2.37	*n.s.*
all users	91	12.6%	48	13.1%	34	13.4%	9	8.8%	$\chi^2_{(2)}$= 1.57	*n.s.*
Total number of statements	346	48.0%	189	51.6%	114	45.1%	43	42.2%		
Total Number of Writers	326	45.2%	179	48.9%	109	43.1%	38	37.3%	$\chi^2_{(2)}$= 5.09	*n.s.*

Fisher exact test was used for those with 0 in the observed frequencies

Engagement, as measured by the total number of statements produced, was highest in the free production modality at 51.6% (189 statements) and lowest in the unified kit at 42.2% (43 statements). The rate of students' engagement, as indicated by the number of writers, followed a similar pattern, with free production having the highest engagement rate at 48.9% (179 writers) and the unified kit the lowest at 37.3% (38 writers), although no significant differences were found (χ2 = 5.09, ns).

Table 5. Category types and examples of descriptions

category	Example of description
Safety	Rounded edges with no sharp edges to prevent children from hurting themselves.
Functionality	More compartments to hold different things.
Durability	Make it sturdy so that it will not break even if it falls.
Convenience	Make it light so that it can be carried and moved easily, even by those who are not strong.
Quality	Varnish the surface to improve the feel, as a rough surface is not good.
Aesthetics	Create a variety of colors to improve the appearance of the product.
Environmental	Use environmentally friendly materials.
Economy	Consider the materials to be used to reduce the cost.

Product Improvement Analysis

There were 956 statements (multiple responses; all valid responses) regarding fabrication product improvement. The free descriptions were classified into eight categories: Safety, Durability, Functionality, Convenience, Quality, Aesthetics, Environmental, and Economy (Table 5).

Across all modalities, students most frequently considered safety (45.2%) and functionality (34.4%) (Table 6). Safety was the highest concern in the unified kit modality (52.0%), while functionality was significantly more considered in the free production modality (40.4%) than in the unified kit modality (18.6%) ($\chi2 = 17.79$, $p < .01$).

Durability and convenience were considered relatively consistently across all modalities, with no significant differences found. However, there were notable disparities in the rate at which students considered quality and aesthetics. Quality was most considered in the free production modality (10.7%) and not considered in the unified kit modality.

Aesthetics were considered to a lesser extent than functional aspects like safety and functionality, which may suggest that practical concerns are paramount in students' minds during the design process. Environmental factors and economy were least considered by students, with only 0.4% and 0.3% consideration rates respectively.

Comparisons were also made by dividing the groups into those that described the user perspective and those that did not (Table 7). The Group with descriptions showed a higher frequency of considering safety (56.1%) than the Group without descriptions (36.5%) ($\chi2 = 27.91$, $p < .01$). Durability was considered more frequently in the Group without descriptions (28.4%) than those with descriptions (16.0%) ($\chi2 = 15.64$, $p < .01$). Convenience was a more prevalent concern for those who provided a description (22.1%) than those who did not (10.1%) ($\chi2 = 19.47$, $p < .001$).

Aesthetics were more often considered by students who did not provide a description (9.1%) compared to those who did (4.0%) ($\chi2 = 7.41$, $p < .01$). No significant differences were found in considering functionality, quality, environmental aspects, and economic factors, indicating a consistent approach to these elements regardless of description.

Table 6. Frequency of responses and chi-square results of analysis of categories related to viewpoint regarding improvement of manufactured products (comparison between the groups of production subjects)

	All (N=721)		free production (n=366)		choice kit (n=253)		unified kit (n=102)		Comparison between groups	
	frequency	rate	frequency	rate	frequency	rate	frequency	rate		
Safety	326	45.2%	168	45.9%	105	41.5%	53	52.0%	$\chi^2_{(2)}$= 3.35	*n.s.*
Functionality	248	34.4%	148	40.4%	81	32.0%	19	18.6%	$\chi^2_{(2)}$= 17.79	**
Durability	164	22.7%	83	22.7%	56	22.1%	25	24.5%	$\chi^2_{(2)}$= 0.24	*n.s.*
Convenience	112	15.5%	52	14.2%	40	15.8%	20	19.6%	$\chi^2_{(2)}$= 1.80	*n.s.*
Quality	53	7.4%	39	10.7%	14	5.5%	0	0.0%		**
Aesthetics	49	6.8%	29	7.9%	17	6.7%	3	2.9%	$\chi^2_{(2)}$= 3.13	*n.s.*
Environmental	3	0.4%	1	0.3%	0	0.0%	2	2.0%		*n.s.*
Economy	2	0.3%	2	0.5%	0	0.0%	0	0.0%		*n.s.*
	957	132.7%	522	142.6%	313	123.7%	122	119.6%		

**p<.01 Fisher exact test was used for those with 0 in the observed frequencies

Table 7. Frequency of responses and chi-square results of analysis of categories related to viewpoint regarding improvement of manufactured products (Group with description or no)

	All (N=721)		Group with description (n=326)		Group with no description (n=395)		Comparison between groups	
	frequency	rate	frequency	rate	frequency	rate		
Safety	326	45.2%	183	56.1%	144	36.5%	$\chi^2_{(1)}$= 27.91	**
Functionality	248	34.4%	114	35.0%	134	33.9%	$\chi^2_{(1)}$= 0.09	*n.s.*
Durability	164	22.7%	52	16.0%	112	28.4%	$\chi^2_{(1)}$= 15.64	**
Convenience	112	15.5%	72	22.1%	40	10.1%	$\chi^2_{(1)}$= 19.47	**
Quality	53	7.4%	19	5.8%	34	8.6%	$\chi^2_{(1)}$= 2.03	*n.s.*
Aesthetics	49	6.8%	13	4.0%	36	9.1%	$\chi^2_{(1)}$= 7.41	**
Environmental	3	0.4%	1	0.3%	2	0.5%	$\chi^2_{(1)}$= 0.17	*n.s.*
Economy	2	0.3%	2	0.6%	0	0.0%		*n.s.*
	957	132.7%	456	139.9%	502	127.1%		

**p<.01 Fisher exact test was used for those with 0 in the observed frequencies

Discussion

Student Attitudes and Experiences

The high positive responses for making things and attending technology classes suggest a strong interest in hands-on activities and the educational experiences provided in these areas. This enthusiasm for practical engagement indicates the effectiveness of the current academic approach in fostering a connection between students and technology.

However, the lower positive response rate for concept and design aspects suggests possible challenges in the more abstract elements of technology education, highlighting an area that may benefit from revised teaching strategies or enhanced curricular focus.

The structured approach, provided by unified kits, appears to resonate well with students, offering a level of guidance and clarity that might be absent in more open-ended tasks. The lower enjoyment scores in free production indicate a need for more support or instruction in the initial design phases of materials processing.

Despite structured kits leading to higher enjoyment and satisfaction in-class activities, this did not translate into a significantly increased interest in pursuing a related career in the future. This disparity suggests that while students are engaged and find value in the educational process, there is a disconnect between their academic experiences and their perceptions of technology-related careers.

User Perception and Product Improvement

The findings indicate a tendency for students to focus on specific users during materials processing tasks, which aligns with the user-centric goals of contemporary design education. However, the minimal consideration for self/family and all users suggests the need for educational strategies that encourage students to adopt a more inclusive perspective during the design process.

The higher engagement levels in free production tasks indicated that when students are given more autonomy, they are more likely to produce more statements about their work. However, this does not necessarily translate into a broader user consideration, as the frequency of considering all users was not the highest in the free production modality.

The significant difference in consideration of functionality between free production and unified kit modalities may indicate that the freedom afforded by the former allows students to explore a broader range of functional possibilities. The need for more focus on quality in the unified kit modality points to a potential area of improvement in structured educational settings.

The minimal consideration of environmental and economic factors highlights an educational opportunity to foster a more holistic understanding of product design. Integrating these considerations into project guidelines and assessment criteria could encourage students to think more critically about the broader impacts of their design choices.

The impact of descriptive engagement on prioritizing design considerations is noteworthy. Students who provided user-oriented descriptions showed a higher frequency of considering safety issues, suggesting that reflective practices may enhance awareness of key design factors. However, the tendency to overlook certain aspects like durability when providing descriptions suggests a need for prompts or checklists to address all relevant design considerations.

Conclusion and Future Issues

This study examined Japanese junior high school students' perspectives on product improvement and user perceptions in materials processing education. Our findings reveal generally positive attitudes towards materials processing learning, with students particularly enjoying hands-on activities. However, we observed a notable disconnect between students' enjoyment of technology classes and their interest in pursuing technology-related careers. This echoes findings by Ankiewicz (2019), who noted a similar gap between attitudes and career aspirations in technology education, highlighting a persistent issue in the field.

Interestingly, structured approaches such as choice kits and unified kits were associated with higher levels of student satisfaction compared to free production methods. In terms of user-centred thinking, about half of the students demonstrated user-oriented perspectives when considering product improvements. Students prioritized safety, functionality, and durability in their improvement considerations, but rarely took into account environmental or economic factors.

These findings have several implications for technology education curricula. There is a need to balance structured and open-ended design experiences, enhance the connection between classroom activities and real-world applications, and explicitly incorporate user-cantered design principles. This aligns with Williams' (2009) emphasis on technological literacy for real-world problem-solving, suggesting that curricula should foster a more comprehensive understanding of technology's role in society.

While this research provides valuable insights, it is important to acknowledge its limitations. The cross-sectional design of the study captures student perspectives at a single point in time, limiting our ability to track changes in attitudes and understanding over the course of their education. Additionally, the study's focus on specific regions of Japan may limit the generalizability of findings to other cultural or educational contexts. The reliance on self-reported survey responses may be subject to social desirability bias or limited by students' ability to articulate their thoughts and experiences. Furthermore, the study's concentration on junior high school students means that findings may not be applicable to other educational levels. Lastly, the study did not extensively investigate external factors, such as family background or prior experiences, that might influence students' perspectives and career interests.

Considering these limitations and our findings, several promising directions for future research emerge. Future studies should employ longitudinal designs to track how students' perspectives and skills in technology education evolve over time, providing insights into the long-term impacts of different educational approaches. Expanding the study to different cultural contexts could offer broader insights into the effectiveness of various approaches to technology education and help identify best practices. In-depth qualitative research exploring the reasons behind the disconnect between class enjoyment and career interest through interviews or focus groups could inform more effective career guidance strategies.

Developing and testing curriculum interventions to address the identified gaps in students' thinking could significantly enhance technology education. This approach is supported by the work of Chikasanda et al. (2013), who proposed a professional development model for technology teachers, emphasizing the need to enhance technological pedagogical knowledge and practices. Future studies should also explore how factors such as family background, socioeconomic status, and exposure to technology outside of school influence students' perspectives and career interests in technology.

To gain a more comprehensive understanding of students' experiences and thought processes in technology education, future research could benefit from mixed methods approaches, combining quantitative surveys with qualitative methods like observations and interviews. Additionally, research into innovative assessment techniques that can effectively evaluate students' development of user-centred thinking and holistic design considerations is needed.

In conclusion, while students show positive engagement with materials processing learning, there is room for improvement in fostering holistic, user-centred design thinking and connecting classroom experiences to future careers. By addressing these issues through thoughtful curriculum development and further research that takes into account the limitations of the current study, we can enhance technology education and better prepare students for the complex technological challenges they will face in the future.

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29.2

Timeless, socially relevant engineering knowledge and skills for future education

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Abstract
What pupils learn in school should ideally be useful throughout their whole lives. It should help them in further studies, in working life, and when acting as responsible citizens in democratic society. This is challenging for all subjects, including technology. Technology develops fast. It is most likely that wheels, wedges, and inclined planes will be used in the future, but it is difficult to know which programming languages, sources of energy, and materials that will be relevant a few decades from now. This article describe how these problems are handled in international curricula and standards, and by Swedish teachers, teacher students, and teacher educators. In curricula they are seldom addressed explicitly, but handled by giving deliberately vague descriptions of what students are to learn. The interviewed teachers, teacher educators, and teacher students were unused to think about future-compliant or timeless knowledge. When prompted to do so during the interviews, they found it easier to describe timeless skills than timeless factual knowledge. Prominent among their suggestions were abilities related to engineering design processes, technical problem solving strategies, fundamentals of computer programming, and engineering mechanics.

Keywords
engineering education, future compliant knowledge, secondary school, technology education, timeless knowledge

Introduction
What students learn in school should ideally be useful both right now and well into the future: it should be timeless or future-compliant. Students learn to enable them to study, help them in their everyday lives, prepare for professional careers, for being able to participate in a democratic society, and more. It is not obvious how an educational system should be designed to increase the likelihood of the studied subject content being valid when the students grow up. The passage of time in itself leads to an inherent transfer problem: Schools mainly teach students about today's society to enable them to function in a society ten, twenty or thirty years in the future. Trying to teach students about the future is difficult, as predictions of the future concerning most aspects of society are notoriously unreliable (e.g., Inayatullah, 1990; World Economic Forum, 2023).

Since the 1990s, content related to technology and engineering has been introduced in curricula all over the world. In some countries (e.g., Sweden, New Zealand, England) it has been in the form of separate subjects while other have integrated it in other subjects, often crafts or natural science (e.g., Finland, the Netherlands, parts of the United States). Predicting future usefulness of technological knowledge is difficult. ITEA's *Standards for technological literacy* (2007, p. 1) describe the situation thus:

> *Because technology is so fluid, teachers of technology tend to spend less time on specific details and more on concepts and principles. The goal is to produce students with a more conceptual understanding of technology and its place in society, who can thus grasp and evaluate new bits of technology that they might never have seen before.*

Technology's 'fluidity' (ITEA's expression) does lead to special challenges. To even identify the 'conceptual understanding' that will withstand the test of time is difficult. Think of how the debates about nuclear power and wind power, the role of mobile telephones, and the use of artificial intelligence have changed during the last decades. Some changes have occurred quicker than expected (e.g., smartphones) while other have been surprisingly slow (we still wait for cold fusion and the autonomous vehicle revolution). In Sweden, what pupils learn about technology in school at the age of 13 should ideally be immediately useful, but also aid them in choosing a suitable branch of secondary education at the age of 16, and to understand political, ethical, and practical technological problems throughout their adult lives (SFS 1010:800, Skolverket, 2024, pp. 12–13, 17). How curriculum designers, standards authors, and educators should address this is not obvious. Future usefulness of technological knowledge has not been a major theme in educational research. In an overview of articles published in the leading journal *International Journal of Technology and Design Education* between 2005 and 2014, future-related terms are absent from the lists of common keywords and seldom occur in article titles (Christensen et al., 2015).

Aim and research questions

The purpose of this study is to find how key players in introductory technology and engineering education (e.g. curriculum designers, standards authors, teacher educators, and teachers) try to increase the likelihood for pre-university (K–12) technology and engineering education to be relevant for the learners later in life. The following research questions have guided the study:

1. What characterises timeless and society-relevant technological knowledge according to key-players in introductory technology and engineering education?
2. How do teachers, teacher educators, and teacher students describe their attempts to include timeless, society-relevant knowledge in introductory technology and engineering education?

Background: Technology education in Swedish schools

The interviews in this study concern the situation in Sweden. The interviewees are Swedish teachers, teacher students, and teacher educators. Many of the problems and opportunities they discuss can also be experienced in other countries, but when they refer explicitly to curricula, syllabi, etc., they talk about Swedish documents and practices.

Swedish youngsters attend compulsory school between seven and sixteen years of age. Technology is a mandatory subject for all pupils, with a total of 200 hours of contact teaching spread out over the nine years. All subjects are described in a similar way in the national curriculum: an introductory text stating the subject's purpose and overarching content, followed by a short list of general skills (three in technology) to be practiced. Core content for years 1–3, 4–6, and 7–9, presented in bullet point lists accompany the skills. The final section contains grading instructions (Skolverket, 2024a, pp. 267–273). The curriculum is open to interpretation, and teachers have opportunities to adapt it to fit their own interests and areas of expertise, as well as their schools'' resources.

Concerning content, the Swedish technology subject in compulsory school is broad, and includes common school-technology content like the design process, materials, introductory computer programming, and technical drawing. Compared with many other countries' subjects, it includes large parts about the history, sociology, and politics of the technological domain.

The nine years of compulsory school are for most students followed by three years of upper secondary school. One of the programmes in upper secondary school is the Technology programme, which prepares students for work or higher education within the science and technology domain. Approximately 8% of Swedish students choose the Technology programme, with considerable regional differences (Skolverket, 2024b). While technology education in compulsory school is for all pupils, upper secondary school is only for those that have chosen it. This leads to the education having a slightly different profile, with more 'hard' engineering content and applied natural science, and less of the historical and sociological perspectives (Skolverket, n.d.).

Method

Data concerning curriculum designers' and standards authors' opinions, suggestions, and visions were collected indirectly through the study of relevant documents. Data concerning teachers', teacher educators', and teacher students' thoughts on timeless technology knowledge and how it should be included in technology education were collected through group interviews.

Theoretical outlook

Douglas Roberts (2007) described two major visions of science education, which are useful for describing technology education as well. *Vision 1* is looking inwards, the need for scientific knowledge is justified by referencing science itself. Science and scientific activities are mainly studied as separated from society and the world at large. This is in contrast to *Vision 2*, where the starting point for education are situations and problems in society. The need for scientific knowledge is justified referencing societal and individual needs. Science is according to *Vision 2* regarded as part of a larger body of knowledge that includes politics, culture, and the ins and outs of everyday life. Whether a *Vision 1* or a *Vision 2* outlook dominates a curriculum, a textbook, or an individual teacher's preferences affects what kind of timeless knowledge that is emphasised. According to *Vision 1*, technical skills, working methods and principle are put forward whereas those adhering to *Vision 2* instead focus understanding of how technology affects and is affected by society, now and in the future. Related to his *Visions*-system is Roberts' (1982) description of *curriculum emphases*. The emphases describe seven types of purposes that are common in science curricula. They provide answers to the question '*Why should pupils learn this?*' Adapted to a technology education context, the answers (purposes, emphases) are: (1) to manage in everyday life (*everyday coping*); (2) to understand how technology functions intellectually (*structure of technology*); (3) to be able to use technological knowledge, e.g. in political decisions (*science, technology, and decisions*); (4) to master processes used in technical tasks (*technological skill development*); (5) to learn what is true (*correct explanation*); (6) for the joy and engagement in explaining technical phenomena (*self* *as explainer*); and (7) to provide a knowledge base for future studies and work (*solid foundation*).

Curriculum, syllabus, and standards analyses

The studied documents include curricula, syllabi, and standards. They represent a convenience sample. All are easily available online and published in any of the limited set of languages that the article's authors read (Danish, English, Norwegian, and Swedish). A rough digital search through the documents, looking for terms like ' future' and 'timeless' was performed. The documents were then read repeatedly, looking for comments about timelessness and/or future usefulness, and content that was relevant for a discussion of timelessness.

Group interviews

The respondents consisted of five groups, gathered through convenience sampling:

- Lower secondary school technology teachers. Three experienced teachers, all former engineers. They work in a municipality-owned school, located in an upper middle-class area near the city centre
- Lower secondary school technology teachers. Four experienced teachers, with varying backgrounds. They work in a municipality-owned school, located on the outskirts of the city
- Upper secondary school technology teachers. Three experienced teachers, all former engineers. They work in a municipality-owned school that is specialised in computer science and invention
- Technology teacher students. Nine former engineers, participating in a bridging teacher education programme at a Swedish university with the aim of becoming secondary school teachers
- Technology teacher educators. Five teacher educators (lecturers, senior lecturers) representing four different higher education institutions in Sweden

Group interviews enable respondents to discuss and develop their answers together. Through the jointly conducted dialogue, they may develop responses further. The interviewers can ask questions to encourage clarification and nudge the respondents if the conversation comes to a halt. Having a safe environment for the interview is important (Marshall & Rosman, 2011). The respondents within each group were well acquainted with each other – they were colleagues at a school, students in the same education programme, or teacher educators who meet regularly. The interviews were carried out at the teachers' workplaces, the students' university, and at a national meeting for technology teacher educators.

The keywords 'Timeless, socially relevant engineering knowledge and skills for future technology education' were written in Swedish on a whiteboard (Sw. '*Tidlösa, samhällsrelevanta, ingenjörsvetenskapliga kunskaper och färdigheter för framtida teknikundervisning*'). These words served as a starting point for the discussion, and both interviewers and interviewees returned to them during the conversation. Each group interview took between 30 and 60 minutes. The interviews were conducted in Swedish. They were recorded (audio only), transcribed verbatim, and translated into English. Data collection was conducted over an eighteen-month period. The first interview took place during the autumn of 2022 and the last one in the spring of 2024.

Analysis of interviews

Analysis of the interviews started with an inductive thematic analysis of the transcripts, based on Braun's and Clarke's (2006) six step method. Patterns and themes were identified and refined through repeated reading. All authors participated in the thematic analysis.

Results and analysis

Curriculum designers' and standards authors' views of timeless knowledge

The content and purposes of technology subjects vary between countries. For example, only some include computer programming. Although most curricula incorporate some kind of design or product development process, there are important differences between them. In some countries (e.g., Finland and Scotland), technology subjects are largely craft based, while others (e.g., New Zealand and Sweden) have a broader approach. This affects how easy and how relevant it is to consider timelessness during curriculum design.

The documents' scopes, styles, and levels of detail varies considerably. Some only contain a framework that allows teachers to fill in the details. Others are detailed and even provide examples of how to teach. Key Stage 3 in the English syllabus for Design and technology (Department for Education, 2013) is an example of the former, while the corresponding Australian document (ACARA, 2015) accords with the latter. The English syllabus consists of three pages in total: an introductory paragraph followed by a list of themes presented as bullet points. By contrast, the Australian document contains approximately 50 pages (including example tasks and a glossary). Another difference concerns which and how much information that is included in subject specific syllabi, and how much that is placed in some general curriculum document that concerns all subjects. The technology subjects also have different overall approaches concerning what the students are to learn. In Roberts' (2007) terms, *Vision 1* dominates the technology curricula of e.g. Scotland (strong crafts focus; Scottish Qualifications Authority, 2012) and Massachusetts (where information and communications technologies are emphasised; Massachusetts Department of Elementary and Secondary Education, 2016). Curricula from Sweden, Denmark, and New Zealand with their social science and history content show clear signs of *Vision 2*. This makes direct comparison between the syllabi awkward, and not very useful. Instead, we will provide an overview of different ways of considering (or omitting) timeless knowledge in curricula and standards for pre-university technology and engineering education.

The overall structure of most technology curricula are similar. They start with a few introductory paragraphs, followed by a list of content areas, and in many cases guidelines for grading. There are a few exceptions, such as the aforementioned voluminous documents from Australia and Massachusetts. These are more like reports about the respective subject, with comments, teaching suggestions, and descriptions of how technology, engineering, and/or STEM studies fit into the greater whole (ACARA, 2015; Massachusetts Department of Elementary and Secondary Education, 2016).

Timelessness and the future in introductory sections of curricula and syllabi

The syllabi's introductions typically contain a short description of why pupils should learn about technology, which often includes comments about future studies, working life (*solid foundation*; Roberts, 1982), and being an active citizen in a democratic society (*science, technology, and decisions*; Roberts, 1982).

The Danish syllabus for technology and natural science (Børne- og undervisningsministeriet, 2019) states that learning in science and technology should be based on pupils' personal experiences and contribute to their overall understanding of the world. They are to develop a STEM related vocabulary, as well as technical skills and ways of thinking that can be useful in everyday life (*everyday coping* and *self as explainer*; Roberts, 1982). Finnish pupils are to develop broad knowledge and understanding of the world: Knowledge in technology and sloyd are important building blocks in this endeavour (*technological skill development*; derived from Roberts, 1982). The syllabus' introduction reminds the reader that humanity is responsible for developing technology in a way to improve the future of nature and society. Pupils should develop knowledge that is useful when working to correct non-sustainable lifestyles. Their responsibilities stretch over multiple generations (Utbildningsstyrelsen, 2014). In the United States, the National Research Council (2013, p. 112) also encourages educators to make sure that pupils learn the bigger picture to prepare them for a responsible life in a complex world where questions concerning science, technology, society, and the environment intermingle (*science, technology, and decisions*; Roberts, 1982).

Technology education for senior students in New Zealand show its *solid foundation* intentions when it 'opens up pathways that can lead to technology-related careers' (Ministry of Education, 2018, p. 1). Even Welsh pupils are to be prepared for working life by learning useful skills, and also be taught about possible careers in technology and engineering (Department for Children, Education, Lifelong Learning and Skills, 2009).

Timelessness and the future in subject contents

As is obvious from the abovementioned examples, curriculum designers commonly consider the necessity to prepare pupils for the future, to provide them with future-compliant skills and knowledge – knowledge that can be useful both now and when they grow up. These suggestions and discussions are however most visible in the syllabi's introductory paragraphs. They are part of the subject's overarching goals, but very little is said about how to make this concrete and tangible in the classroom. Teachers and textbook authors have to take responsibility for the implementation.

The main strategy for describing timeless knowledge is by using very general terms and expressions. For example, the Irish syllabus for design and technology includes a section about materials technology. It states that students should learn about properties of materials, materials processing, surface treatments, quality assurance, etc. (National Council for Curriculum and Assessment, 2006, pp. 35–36). The section does not mention any single material, but only families: metals, wood, composites, polymers, fabrics, and ceramics. An advantage of this is that the syllabus is reasonably future-safe. Most materials that were in widespread use when the syllabus was written fit into these categories, as do most materials invented since then. A drawback is that teachers get very little guidance concerning prioritization and which materials to include. All materials are probably not as important. Both ivorite (an early 20th century plastic) and polyethylene (which is in widespread use today) belong to the family of plastics. Nevertheless, it could be argued that they are not as important to learn about (at least not important in the same way). Another drawback is that not all potentially interesting materials fit into the listed categories, however inclusive. A teacher who wishes to include newly discovered allotropes as graphene and fullerene gets no support from the curriculum, even though many materials scientists believe that they will become important in a near future (Geim & Novoselov, 2007).

Similar strategies are used to describe skills that students are to master. The descriptions are abstract, and thereby likely to be timeless. The Swedish syllabus for technology states that students are to learn about the different phases of the product development process: identification of needs, proposal of solutions, design and testing, etc. (Skolverket, 2024a). This can be applied to almost any described design process, from the ‘water fall’ or ‘over the wall engineering’ models of the 1970s to the agile methods of today (Abbas et al., 2008). The syllabus’ description of the subject content is timeless by containing very little information. Teachers get next to no guidance for their decisions. Whether they should teach established methods that are easy to grasp, or modern ones that supposedly are more efficient is not stated by the syllabus.

The Swedish curricula and syllabi

The introduction to the Swedish curriculum describes the purpose of schooling, and states that pupils should learn to make informed decisions concerning their own futures. A historical perspective should permeate all school activities, preparing pupils for the future and ‘develop their ability to think dynamically’ (Skolverket, 2024a, pp. 15, 36,6 quote from p. 8). The Swedish technology subject (Skolverket, 2024a, pp. 267–273) has no explicit future perspective. The term ‘future’ (Sw. ‘*framtid*’) is nowhere to be found in the syllabus, but perspectives of timelessness and the future are implicit in expressions dealing with sustainable development or development in general.

In upper secondary school, timelessness and future perspectives are not mentioned explicitly in the syllabus, but can be seen as included implicitly in statements about sustainable development, entrepreneurship and preparation for working life (Skolverket, n.d.). To what extent and in what forms ideas about timeless and future-relevant technological knowledge manifest in technology education in compulsory and upper secondary school in Sweden is mainly up to the teachers. The curricula and syllabi provide very little guidance and support.

Teachers’, teacher educators’, and teacher students’ views of timeless knowledge

When comparing statements from the different groups of respondents, both similarities and differences came up. These concern what kinds of themes that were discussed, and how they were addressed. The lower secondary school teachers highlighted examples from their own teaching practices. They repeatedly returned to what pupils would find interesting or difficult. They also made more frequent references to the curriculum documents than the other groups. The upper secondary school teachers stressed the need to be skilled in maths for a future career in technology, which the lower secondary school teachers did not. The teacher educators focused on the challenges of teachers and teacher students. They talked about how teachers should stand up and be proud of their subjects, and the need for courage and self-confidence for the ability to teach. The participating teacher students, of whom many had recently worked in engineering, referred to their own experiences as pupils and students. Just like the upper secondary school teachers, they mentioned maths as essential for careers in technology or engineering, but also self-confidence, initiative, and curiosity.

For all respondents, it seemed challenging to discuss the abstract concept of timeless knowledge, or even knowledge that would stay useful over time. In many cases, the discussion drifted towards engineering skills and abilities ("knowing how"). Propositional knowledge (facts, "knowledge that") stayed in the background for most of the time. Even though the questions posed and the starting point slogan concerned knowledge, the discussion in many cases drifted towards attitudes, feelings, and values.

Digital tools, systems understanding, problem solving, engineering design, and a curious but critical attitude were among the central aspects of timeless, socially relevant, engineering knowledge that the teachers, teacher educators, and teacher students discussed. Below, these are organised as themes that emerged from the entire material, across all participant groups.

Timeless facts as content in technology education

The respondents highlighted certain facts and content in different technological areas that they believed would remain relevant, and referred to these as 'timeless', 'necessary for all engineers', and 'indispensable parts of technological literacy'. They were considered important mainly for their usefulness in future studies and in everyday life (*solid foundation*, *everyday coping*; Roberts, 1982). The most commonly mentioned areas were computers, programming, electronics, energy, and mechanics. The lower secondary school teachers highlighted technical systems and the built environment. The upper secondary school teachers also mentioned the history of technology.

Fundamental programming concepts such as variables, conditional statements, and loops were considered central concepts that will withstand the test of time. The secondary school teachers also mentioned common electronic components, their names, and use. The upper secondary school teachers stressed the need to understand how to combine electronic components with computers and processors to perform automatic control tasks.

> *If you want to be more hands-on, so that skills and knowledge … Then we say in technology that those students learn CAD, programming, and electronics as a common thread; so they can manufacture all sorts of things.*
> (*Upper secondary school teacher*)

Teachers, teacher educators and technology teacher students all mentioned classical mechanical technological solutions such as levers, inclined planes, and screws. One of the teachers reminded the rest of the group that they are truly timeless: 'they have been at the core of technology education since antiquity and will be used forever.' In another group interview, these fundamental mechanical principles are compared to standard features in programming languages:

> *You want to get in early with what you were talking about basic components – wedge, screw, inclined plane, those things – to get an understanding that you use it. It is a bit like physics. This is however applied physics, which fits the technology subject. But programming and such, it also has basic building blocks: that you can do a loop, that you have a choice of different options. That is just like the wedge, and the screw, and the inclined plane. They are basic building blocks that can be combined, just as programming has its basic building blocks.*
> (*Technology teacher student*)

Energy, especially the production of electricity, which is an important political question, was also mentioned numerous times (traces of *science, technology, and decisions*; Roberts, 1982). The discussion never really took off, however. The reason for this could be that energy, energy distribution, and energy politics, traditionally belong to the subjects of physics and civics in Swedish curricula.

Timeless methods and ways of reasoning

It was obvious that the respondents found it easier to discuss timeless methods, procedures and ways of working and reasoning, than propositional content knowledge. The selection was mainly motivated by its usefulness in future studies and work, and for the joy of knowing (*solid foundation*, *self as explainer*; Roberts, 1982). Several times, strong beliefs in the possibility of transferring a method or a way of working from one domain to another were expressed. This concerned areas such as the writing of technical reports and being able to carry out a general engineering design process, applicable for many kinds of technical problem solving or product development tasks.

> *To be able to work with the design process based on models and in that way be able to solve problems and that it can be some kind of core of knowledge.*
> (*Technology teacher educator*)

Teaching a structured design process has been the core of technology education in many countries for a long time (probably most notable in England). The Swedish technology curricula have always described a broader subject, in which design and product development is just one theme among others (Skolverket, 2024a, n.d.). Nevertheless, even in Sweden the learning of a design process is considered essential and timeless technology education content. The upper secondary school teachers mentioned how product development and engineering design work encourage curiosity and provide a framework for learning about general technological phenomena. The lower secondary school teachers also mentioned this, for example in relation to learning about how to write technical reports and how to use flowcharts and technical drawings. The teacher students talked about the importance of learning how to reason and collaborate, and how design and development work could provide an environment for this.

> *It starts with – among other things – what product development actually is, and some examples of products. Where do the products come from? What are the driving forces behind why these products have been invented? Why do they exist? And discuss it … The products we have chosen are Swedish or where Swedes have been involved, such as mobile phones, milk cartons and refrigerators. We start the discussions from there. How is it that? What was it like before there was a need? How has it evolved over time?*
> (*Lower secondary teacher*)

The upper secondary school teachers, of whom many were keen on programming, mentioned software engineering as an important form of design or product development work. They described the procedures for systematic testing, analysis, and debugging of software as to some degree transferrable to other technical domains:

> *The students have practiced this a lot. To identify target groups, do test cases, improve their products, and think in an innovation-way; all this stuff that they just try to express.*

> *The knowledge they have then gained through CAD, electronics, and programming, and other things … They can use it to build a work of art with technology, and express something that is important. There I think that we have trained both of these aspects: both going into oneself and going out to get feedback from others. And it works, the students can transfer this knowledge from the technical context and later use it for something else.*
> (*Upper secondary school teacher*)

Preparation for future studies, everyday life, and work

Many respondents stress the necessity for students to develop a positive attitude towards technology, both for further studies and for managing their daily lives. The respondents expressed how technical self-confidence, interest in technology, and higher studies in technology are timeless, and in need of constant further development. Certain skills and abilities are highlighted. Despite our questions focusing on knowledge and skills, the need to develop sound attitudes towards technology and engineering was brought up numerous times. The respondents described how a timeless, socially relevant, engineering-focused attitude must be positive towards and comfortable with technology. The subject have to be permeated by a desire to investigate, discover, and solve problems, combined with a will to understand one's choices and opportunities to work hands-on with different technologies. The respondents emphasised the importance of practical applications and that the educational system constantly needs to evolve to prepare students for lifelong learning and adaptation to new technological advances. Especially the upper secondary school teachers highlighted that an innovative attitude can open doors and improve opportunities.

The respondents underscored the importance of a basic understanding of technology, the ability to solve problems, and the significance of being able to navigate in an increasingly digitalized world. A part of this is the need for rudimentary knowledge of computers and computer programming, by some respondents referred to as 'computational thinking' or 'general digital competence'. To varying degrees, all respondent groups described this as necessary for future studies, work, and everyday life (*solid foundation, everyday coping*; Roberts, 1982).

> *Since everything is becoming increasingly digital today, one could argue that programming is part of fundamental technological knowledge. You should easily understand how all these systems work on a rudimentary level, how the code looks, and how it is accepted, then what it is and what capacity it has. There is a lot of talk about AI and machine learning today, but at its core, it is based on statistics.*
> (*Technology teacher student*)

This underscores the importance of basic programming knowledge and understanding of statistics (which is part of the Swedish mathematics subject) and digital systems as timeless and necessary competencies.

The respondents also emphasise the significance of students' developing an understanding of large technical systems, and the systems' interactions with society. This knowledge can enrich students' academic journey and equip them with skills to effectively and efficiently navigate and influence complex systems in their daily lives and future professions, and better understand the relations between technology and society at large.

Furthermore, the upper secondary school teachers pointed out that engineering design work encourages information retrieval skills and critical thinking. If the project is large enough, and authentic enough, pupils will repeatedly run into problems that neither they nor their teachers know how to solve. Efficient use of a search engine is therefore considered a timeless skill for engineers and technicians. The upper secondary school teachers remarked that internet searches often can be quicker than trying to find the answer in a textbook or handbook:

> *Google it, and see what you can find. There is a lot of rubbish out there, but also useful stuff. You learn how to find it by trying.*
> (*Upper secondary school teacher*)

Environmental awareness, life cycle analysis, risk assessment, and mathematical and physical modelling are also considered timeless skills that can be practiced in a design process environment. An attitude towards technology that will withstand the test of time is also described as action-oriented, curious, and insightful about how the world works. Throughout the educational system, students should be encouraged to develop a personal desire to learn and a willingness to face technical problems that they cannot yet understand.

Application of societal, political, ethical, and existential questions

Environmental impact or ethical implications of technologies were mainly discussed in terms of attitudes. The respondents discussed the need for pupils to develop an environmental awareness, and recognize their own (and the Western world's) roles in the technosphere. They did however not discuss how this could be achieved, or how these attitudes could encourage scientific evaluation of the impact of lifestyle choices or novel innovations. The suggestions never went beyond developing a general awareness of possible problems, and the need for a positive attitude towards the possibilities of finding solutions. The respondents talked about how an innovative, self-directed, and playful attitude is important for students' will and abilities to approach timeless, socially relevant, and engineering aspects with their mental 'problem-solving toolkits.'

The respondents also highlight the importance of understanding how political decisions and economics affect technical development. An example that came up concerned factors that influence electricity prices in Sweden. To develop an overview of this and being able to discuss the combined impact of technology, policy, and international trade, is considered to be both important and timeless, especially by the secondary school teachers. Related to this is the respondents' focus on social responsibility, ethics, risk assessment and inherent values in technology and engineering (traces of *science, technology, and decisions*; Roberts, 1982). This includes insights into how technology affects the environment and emphasises the importance of sustainable development:

> *I think a lot about the social responsibility that comes with the knowledge about technology. It can be managed and refined with some sort of sense of values and ethics. Especially if you think about technology education in compulsory school, where it is mandatory, it is important that it benefits society as a whole. More so than in upper*

> *secondary school.*
> (*Technology teacher student*)

These statements highlight how social responsibility and environmental awareness may be integrated in technology education, and underscore the need for a precautionary principle when applying technical knowledge. The respondents talk about how deep understanding of systems thinking is crucial for effectively managing technical and societal challenges.

Discussion

That students are supposed to learn for the future is challenging for curriculum designers, textbook authors, teachers, and the students themselves. This is true for all subjects, but introductory technology and engineering have many special difficulties. One is of course that technology is prone to change. Humanity will almost certainly use wheels, resistors, and concrete thirty years from now. Whether the programming language Python, small modular nuclear reactors (SMRs), and combustion engines will be in widespread use is not as certain. It is difficult to predict what should be prioritised in technology education for best outcome.

Handling timeless knowledge … or not

Curriculum and syllabus designers have addressed the challenge of identifying timeless knowledge mainly in two different ways. They have either ignored it or tried to handle it by describing the content of their subjects so vaguely that they become timeless through their lack of real substance. The Swedish technology subject is an example of the latter. One of the overarching learning areas is 'knowledge of technological solutions and how constituent components work together to achieve suitability and function' (Skolverket, 2024a, p. 268). It is a goal that seems reasonable in a Stone Age context (sticks, strings, and a sharp stone make an axe), today (metal tubing, wheels, pedals, chain, and sprockets make a bicycle), and in the future. Through its vagueness, the curriculum manages to be future-safe. It does however say very little about students' intended knowledge. If they learn about the components of a bicycle, will they be able to use this knowledge in other contexts? If bicycles are no longer used, or just their chains replaced, the value of today's knowledge of bicycles and their components is reduced. If the students have achieved some abstract, general component–whole knowledge (a form of systems thinking) it could be applicable in a variety of contexts and therefore useful. Otherwise, their knowledge will be of historical value only. It is obvious from curriculum studies that the main responsibility to create a technology subject that encourages learning that will withstand the test of time rests on the teachers.

Teachers, teacher students, and teacher educators expressed ideas about on the one hand timeless skills, abilities and attitudes, and on the other hand propositional knowledge. Most responses concerning future usability of technological knowledge concerns future studies (*solid foundation*; Roberts, 1982). Among the skills, they mentioned the ability to follow a structured engineering design or product development process, and to write a simple computer program. Curiosity was mentioned as an important attitude, especially if combined with an ability to critically evaluate various technologies (positively or negatively). Suggestions for which propositional knowledge that will be useful in the future were not as numerous but included the five simple machines from antiquity and fundamental constructs from computer programming.

The purpose of technology education
It is obvious from the teachers' answers that they do not really agree about the overarching purpose or vision of the technology subject. The former engineers now working in technology education were obviously influenced by their earlier careers when thinking about technology and technology education (compare Fahrman et al., 2019). They emphasised the necessity to learn about design processes, electronics components, and computer programming without making explicit references to non-technical phenomena. Their students learn about technology for technology's sake (*Vision 1*; Roberts, 2007), to prepare for future studies and work in the technological domain (*solid foundation*; Roberts, 1982). Among the other lower secondary school teachers, social responsibility and ethics are put forward. As stated above, they discuss the energy system and its environmental and economic effects. This is a problem complex typical of Roberts' (2007) *Vision 2*, complex and value-laden.

Timeless abilities and skills
The skills and abilities that are put forward by the respondents belong mainly to the domains of traditional subject content in introductory technology and engineering education: project work, technical drawing and sketching.

The upper secondary school teachers also highlight the necessity to be able to use internet information sources efficiently. To what extent learning to use the search tools of today will be of help in the future is of course hard to predict. Since the introduction of large-scale search engines in the late 1990s, the trend has been towards ease of use. The need for information literacy and ability to evaluate sources of information will most likely still be indispensable, but to what extent there will be a need for search training is very difficult to estimate.

Timeless attitudes and ideals
The respondents repeatedly talk about on the one hand curiosity and an open mind, and on the other hand a critical, questioning attitude when it comes to technology. Interestingly enough, none of them described or even provided examples of activities and content that encourage this.

Timeless propositional knowledge
Factual knowledge is the area in which the respondents have the greatest difficulties concerning finding proper answers to our questions.

Many themes described are closely related to the skills and abilities: students are to learn the names and functions of electrical components to be able to use them in systems for automatic control, for example. The propositional knowledge thereby becomes closely connected to the abilities and skills, which is typical of the technological domain (Norström, 2015).

Somewhat surprising, there were very few comments concerning how technological artefacts and systems work and/or are part of the infrastructure. It could be argued that knowledge about for example nuclear power and its radioactive residue will be useful in the foreseeable future. In spite of this, none of the respondent groups mentioned it.

Conclusion and future studies

The necessity of timeless knowledge is inherent in the very idea of schooling. The purpose of students' learning lies in many cases far into the future. Their knowledge should be useful in future studies, working life, and for being able to be an active member of democratic society. Judging from our curriculum studies and interviews, this has not been adequately addressed in technology education. Teachers get very little support and have few guidelines that could help them to take the perspective of timeless or future-compliant knowledge seriously.

The interviewees were teachers, teacher educators, and teacher students. They were however few and not randomly selected. They had different backgrounds and worked in schools of different kinds. Exactly to what degree their ideas and experiences are typical is therefore impossible to know, but it is likely that similar understandings (or lack thereof) are common in schools elsewhere. The interviewees were clearly unused to discuss students intended learning from a future-oriented perspective. Their mentioned examples were mainly skills related to design and programming. characterised by their usefulness mainly in future studies and in everyday life. Political implications of technology and engineering were mentioned briefly in connection with electrical energy. Nobody mentioned any strategies or methods for making sure that the subject content is still valid and relevant.

This study has an exploratory approach. It would be very interesting to conduct follow-up studies with teachers and teacher educators in other countries. It would also be interesting to conduct a thorough study of textbooks, teachers' handbooks and other artefacts intended to support teaching and learning. Preliminary studies of Swedish textbooks indicate that they do not compensate for the shortcomings of the curricula.

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Insights into Sustainable Development: Secondary School Students' Conversations about Product Life Cycles

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Abstract
In this study, we provide insights about secondary school students' conversation about products' life cycles in relation to three dimensions of sustainable development: economic, social, and ecological sustainable development but also what traces of view that appear in these conversations. Production and consumption are part of complex technological systems that affect nature and life on earth, and knowledge about these systems are required to achieve sustainable development. In technology education, students can have the opportunity to talk about products and their life cycles. Hence, this study aims to explore what emerges in students' conversations about products' life cycles in relation to sustainable development. Data collection was conducted in Sweden through seven semi-structured interviews, with in total 21 students participating in groups. All student responses have been analysed using thematic analysis to explore dimensions and views of sustainability. Results show that the students discuss with regard to all three dimensions of sustainable development. However, the phases of a product's life cycle occur to varying extent within the different sustainability dimensions. Additionally, the students also connect dimensions with both harmonious and contrasting perspectives but also talk about the dimensions isolated. When participating students discuss, traces of mainly anthropocentric and technocentric view emerge. This has implications for technology education, where for example deliberative conversations can be used for engaging students in sustainable development.

Keywords
Technology education, Sustainable development, Product life cycle, Student Conversations, Views on Sustainability

Introduction
Today's society is characterized by rapid consumption and increased production (Stables and Keirl, 2015), making the concept of the product life cycle in relation to sustainable development a centre of a gradually urgent discussion. These production and consumption patterns form complex technological systems that significantly impact the environment and overall planetary well-being. Growing awareness has highlighted that traditional consumption and production are not a reasonable path forward (United Nations, 2015). Furthermore, to achieve Global Goal 12 of the Sustainable Development Goals, it is essential for people to have relevant information

and awareness to ensure sustainable consumption and production (Global Goal 12.8 in United nations, 2015).

In this context, education plays a critical role as a catalyst for change by building understanding and developing the skills needed to address these complex issues (UNESCO, 2005). Within this, technology education plays a crucial role. Traditionally, technology subjects rests on a foundation of design and manufacture (McGarr and Lynch, 2021), where problem solving through product design is a reigning paradigm (Stables and Keirl, 2015). However, evaluating technology and assessing its impact are also integral to curricula for technology education in for example Irland, New Zeeland, and Sweden (McGarr and Lynch, 2021; Ministry of Education, 2018; Skolverket, 2022). Within this content, understanding of and knowledge about product life cycles is essential in conscious designing and evaluation of technology for sustainable development.

Additionally, students should also develop skills and attitudes to foster sustainability awareness (Bianchi et al., 2022). In today's society, we face a range of challenges related to sustainability, including climate change, resource reduction, and social inequality. Meeting these challenges requires an in-depth understanding of how various factors interact. For these reasons, insights into students’ perspectives on sustainable development and product life cycles are crucial for developing technology education for sustainable development.

In this study, we contribute to these insights by analysing students' conversations about product life cycle in relation to sustainable development. Building on a preliminary study (Sundler & Hultmark, 2023) presented at the PATT40 conference, this study expands the research to include seven student groups (21 lower secondary students) from different schools in Sweden. The analysis has been deepened, and a new research question has been added to explore students’ views on sustainability.

Background

Over the years, various reports and studies have outlined different sustainability competences. Recently, Scalabrino (2022) reviewed 36 studies on Education for Sustainability, forming the basis for the European Unions (EU's) sustainability competences GreenComp (Bianchi et al., 2022). GreenComp aims to shift values towards protecting our planet and emphasises integrating sustainability into education and training systems to benefit both planetary and public health. It includes knowledge, skills, and attitudes under 12 competences.

According to Bianchi et al. (2022) valuing sustainability involves reflecting on personal values and recognising diverse approaches to sustainability. These moral and philosophical approaches shape various assumptions and arguments, highlighting the necessity to identify multiple values and explain how they differ among individuals but also over time. It is also essential to gain knowledge to critically examine the extent to which these values are consistent with sustainable development. Exploring the inherent tensions and complexities of sustainability issues is crucial to promote successful learning about sustainable development. This means that teaching cannot only address the individual dimensions of sustainability - social, ecological, and economic - but also needs to show how the dimensions interact and influence each other within a technological system. Systems thinking, included in the GreenComp-competences, involves viewing sustainability problems from multiple dimensions and understanding how the different parts of the system interact (Bianchi et al., 2022). By examining these interactions, a deeper insight can be developed into the challenges and opportunities for achieving sustainable development (Herremans & Reid, 2003; Sterneäng & Lundholm, 2012). Teaching for sustainable development advocates for a holistic perspective with a pluralistic approach, emphasising the interconnectedness of economic, ecological, and social dimensions (Berglund & Gericke, 2016). Within this lays contradicting and harmonious perspectives that can be hard to balance.

In a study by Öhman & Öhman (2012), students related the sustainability dimensions to each other but tended to describe the dimensions as harmonious, without contradictions or conflicts. Gustafsson & Warner (2008) suggests that engaging students in deliberative conversations, structured dialogues that encourage participants to explore different viewpoints and critically reflect on their one, can raise awareness of sustainability's complexity, promoting a deeper understanding and engagement for these issues. Additionally, such conversations promoting critical thinking and foster the development of skills needed to make informed and sustainable decisions. This greater self-involvement can ultimately lead to action competence in students.

Sustainable development is widely recognized as a crucial component of technology education (e.g., Elshof, 2009; Pavlova, 2013; Stables & Keirl, 2015). Elshof argues that technology education has a responsibility to create a new sustainable way forward by encouraging students to think and act differently about how they use, consume and design technology. Technology education should teach students to design products with social, economic, and ecological sustainability in mind where both human and non-human nature is valued (Pavlova, 2011). This emphasises that the views on sustainable development and what values are incorporated in these views holds significance, and students should be given the opportunity to develop these views within the frame of technology education.

Svensson and Von Otter (2018) showed that teachers' perceptions and teaching of technology and sustainability revolve around three themes: recycling thinking, consequential thinking, and systems thinking. The teachers felt it is important for students to gain an understanding of how a product is made, used and recycled. Additionally, they aimed to promote awareness of how technology impacts the environment, encouraging students to reflect on ethical dilemmas linked to technology consumption. Finally, systems thinking emerged as the third theme, encompassing three content categories when technology and sustainability were integrated: product life cycle analysis, material analysis and technological systems. Teachers and pre-service teachers also view sustainable development as interdisciplinary, covering topics like consumption, health, environment, justice, energy, resources, and economy (Bursjöö, 2014).

While there is research on teachers' views on sustainable development in relation to product life cycles, few studies focus on students' expression and views on these topics. For example, Juntunen and Aksela (2014) demonstrated improved argumentation skills among students through a life-cycle analysis project. However, more research is needed concerning sustainable development in relation to product life cycles from students' perspectives.

Aim and Research Questions

In technology education, students should be given the opportunity to learn about products' life cycles and relate them to sustainable development. Knowledge about how students talk about consumption and production linked to sustainable development is important for practitioners in technology education as well as for further research. However, there is limited research on this. Hence, the aim of this study is to explore students' conversations about sustainable development in relation to product life cycles with a focus on dimensions and views of sustainable development. This was done with guidance of the following research questions.

Research questions

1. What emerges from students' conversations about the life cycles of products in relation to dimensions of sustainable development?
2. How are the dimensions related to each other in the students' conversations?
3. What views on sustainability can be traced in students' conversations about the life cycle of products?

Theoretical framework

In this study, the concepts of sustainable development, product life cycle, and views on sustainability are of importance. To theoretically frame sustainable development, we used guidelines from the United Nations Commission for Sustainable Development (United Nation, 2001). This framework defines sustainable development through three main dimensions: *environmental*, *social*, and *economic*. Developed to form indicators for corporate social responsibility, it specifies factors for each dimension. The social dimension includes the factors equity, health, education, housing, and security. The environmental dimension covers atmosphere, land, oceans, seas and coasts, freshwater, and biodiversity. The economic dimension addresses consumption and production patterns and economic structure. These dimensions and their associated factors were employed in our study to sort students' conversations.

The product life cycle can consist of different phases. In this study, we view this life cycle as consisting of four phases: *Production*, *transportation*, *usage & retail*, and *disposal*. The production phase includes activities to prepare products for usage such as designing and manufacturing, while the transport phase includes all transports made from manufacturing to usage. The usage & retail phase includes retail, sales approaches and customer use. The last phase, disposal, includes any handling of products after the intended usage. This has been adapted from the phases used by Vaesen (2012) with modifications to be relevant in the context of technology education.

There are different moral and philosophical views on sustainability. In this study we use *anthropocentrism*, *technocentrism*, and *ecocentrism* as theoretical frame. Anthropocentrism places humans at the center, viewing natural resources primarily as means for human use and benefit. In contrast, ecocentrism prioritises nature considering humans as part of the natural ecosystem and emphasising the well-being and balance of nature (Dobson, 1996). Technocentrism focuses on technology as the key to solving environmental and societal problems (Bianchi et al., 2022). Pavlova (2011) suggests weak anthropocentrism as a more balanced approach in technology education, which seeks to harmonise human needs with respect for nature´s rights and well-being. This view encourage a holistic approach to sustainability, integrating ethical and moral values which can underpin design projects in technology education.

Method

Data collection

To obtain a rich dataset (Robson & McCartan, 2016), data were collected through seven semi-structured interviews, where 21 ninth-grade students (15-16 years old) participated in groups. These students were from seven different schools across Sweden. The participant selection was subjective (Denscombe, 2018) to obtain a geographically and socio-culturally diversity among the schools. Additionally, one school was included because it was sustainability certified by the Swedish National Agency for Education, highlighting its commitment to address sustainable development (Swedish National Agency for Education, n.d).

Group interviews were conducted to stage a possible classroom situation where students discuss product life cycles based on given questions. In group discussions, students' conversation can be enhanced when they are stimulated by each other's thoughts and comments (Robson & McCartan, 2016). Open questions related to the product life cycle were asked, with follow-up questions from the interviewer or another student. For example, the question used to prompt conversation about production was: “What do you know about the production of things like clothes and footballs, or mobile phones?” The approximately 50 minutes long interviews were audio recorded and subsequently transcribed manually.

Analysis

The data was analysed through thematic analysis, as described by Braun and Clarke (2006). During the analysis process, the authors adopted an interpretive approach regarding what the students were expressing. From the theoretical framework, a code-scheme was established (Table 1). The transcripts were read and reread, and an initial coding of the data was performed separately by two authors using the code-scheme. The coding was then discussed, and any uncertainties in the coding were resolved.

Table 1. The code scheme used in the thematic analysis.

Sustainable development	Product life cycle	View
Social dimension Ecological dimension Economical dimension	Production Transportation Usage & Retail Disposal	Technocentric Ecocentric Anthropocentric

Afterward, sections that were deemed relevant to the research questions were selected and a repeated deductive coding of the relevant sections were conducted jointly by two authors, combined with inductive coding for context. The students’ statements were then sorted based on dimension of sustainable development and phase of the product life cycle and from this sorting deductive themes were constructed to answer research question (i). In a subsequent stage, themes were constructed from the deductive codes to answer research questions (ii) and (iii). The construction of themes was made from similar patterns of meaning across the dataset, paying close attention to the research questions and the theoretical framework. The themes were evaluated, and through discussion among the authors, the themes were refined to have clearer distinctions from each other.

Ethical considerations

The research adhered to ethical principles to protect students´ privacy. The Swedish Ethical Review Authority reviewed the study's approach and data management plan and gave its approval for the implementation. Following the Swedish Research Council´s ethical guidelines (2017), the school principal and teachers were informed about the study´s purpose, voluntary participation, result usage, and contact details. Students received a separate letter with this information, emphasizing voluntary participation and anonymity. All participating students were over 15 years old and were therefore considered capable of giving informed consent. Those who chose to participate provided written consent, and their legal guardians were informed beforehand. Additionally, all names used in the article are fictitious to further ensure confidentiality.

Results

The thematic analysis revealed that students encompassed all three dimensions of sustainable development: social, ecological, and economic. However, their consideration of the phases of products’ life cycle varies in emphasis across these dimensions, and certain phases are more prominent related to specific dimensions. Furthermore, the students interconnect these dimensions, sometimes harmoniously, illustrating their ability to complement each other. At other times, they contrasted the dimensions and highlighted conflicts or trade-offs. There are also cases where students discuss each dimension in isolation, without connecting them to the others. The views that can be traced from the students’ conversations predominantly reflect anthropocentrism and technocentrism. Meaning that the students often focused on human-centred considerations and technological solutions when contemplating sustainable development. Here follows a deeper description of the results.

What emerges in students’ conversations about the life cycles of products in relation to sustainable development?

In the analysis, when students talked about the social dimension of sustainable development it was mainly in terms of the production of goods. When addressing the economic dimension, they primarily talked in connection to usage and retail as well as transportation. In contrast, when the conversation turned to the ecological dimension, students covered all stages of the product life cycle.

The Social Dimension

The students’ conversation was primarily centred around the production of goods when they talked about the social dimension. In the group interviews, the focus predominantly centred on working conditions and resource use in production, particularly within the cotton industry for cloth production. Here, students frequently highlighted that cotton is a water-intensive crop and its impact on water resources. They discussed how water is essential for basic needs, such as drinking and hygiene and that water consumption affects people's living conditions. They highlighted that cotton is cultivated in countries that already have water shortages, which worsens the situation. They cited the severe degradation of the Aral Sea´s water level due to cotton production, which affects people's living conditions.

The students also identified production locations, including China, India, Bangladesh, and the USA, noting that some of these countries lack democratic governance. They emphasized the prevalence of child labour and poor working conditions commonly found in the production industry. For example, in Excerpt A, students were talking about working conditions and child labour. Alice said that workers struggle financially on their salaries and have long working days and experience significant exhaustion. This not only impacts their health but also affects their life expectancy and overall lifetime earnings. Alex continues and claims that dangerous substances in the work environment cause poor health and premature death. Jane highlights that these countries have a low Human Development Index (HDI), but that this would increase if children were educated rather than being forces to work.

Excerpt A

Alice	But it's not just child labour, it's working conditions in general with long hours and low pay. They wear themselves out until ... so they don't live very long, so they don't have the energy left to work when they get older, which means that they can't earn as much money and they can't live on what they earn because the salary is far too low.
Alex	In many cases it is also ... it can be really dangerous environments they work in. Poisons and so on are very often used, and it is allowed in many countries to use life-threatening pesticides and so on, where many people die or are seriously injured.
Jane	But in the cotton industry, this happens every year and many people are poisoned. Another problem with child labour is that it is negative for the country in the end because they are not educated, so they can't help move society forward, that's what I was going to say. So what is it called? Their D..i..
Nina	HDI
Jane	Yes, their HDI is low, and it could be increase if the focus was on educating children for just one more year.

When the student groups talked about the social dimension, they did not address transportation or usage and retail. Disposal was only referred to briefly when they said that unused food can be prepared and given to people in need.

The Ecological Dimension

When the conversation revolved around the ecological dimension of sustainable development, students talked about all aspects of the product life cycle. In relation to usage and retail, the students reflected on their own consumer behaviors and thought processes when purchasing goods. They emphasized the impact of consumption on the environment, and many expressed that they try to reduce their consumption by minimizing clothing purchases and maximizing the lifespan of clothes to reduce new purchases. Additionally, several students mentioned that they buy second-hand clothes because it is better for the environment. They discussed the impacts of online shopping versus purchasing directly in stores, acknowledging that both affect the environment and result in emissions. In the conversations, they stated that instore shopping allows the opportunity to try on items directly to ensure proper fit, while online shopping often results in unnecessary transportation when returning unwanted goods. According to their statements, returns can involve shipping items to other countries for inspection and repackaging, thereby increasing the environmental impact. An example of this can be seen in

Excerpt B, where the student stated that it is environmental better to buy items in stores than online.

Excerpt B

Liam	Buying in a store is better than buying online, that is, if you think environmentally, because if you buy in a store then you just take it and go home, but if you buy from a website, it may be long shipping.
Olivia	Yes, because if you buy on a website, it's just your package that will be shipped to you if we say that you buy in-store, it's like a large amount. And then when you order online, it may not fit, but if you instead buy in-store, you can try it on and then you don't have to order maybe three sizes because it's free return and then it's sent back. It was on the news that it is sent to Poland to be repackaged and refolded and it is as if it is first sent from a warehouse to your home, you try on your clothes and one size fits, you send back the rest that ends up in Poland and then back to Sweden. It's like a whole transport extra than if you actually went to the store and actually just tried it on and just bought a garment.
Ava	Yes, exactly, because in the store you can return the goods directly there in the store if something does not fit. So it is more sustainable to buy in the store, then it is not sustainable to buy new clothes all the time because it emits so much.

In connection to disposal, several students stated that it is more beneficial for the environment if products and resources are reused. Students highlighted the importance of recycling, noting that raw materials can be repurposed into new products. They also pointed out that donating clothes and other items to second-hand stores is considered both climate- and environmentally friendly.

The students discussed various modes of transportation and they considered environmentally friendly methods for transporting goods. They stated that transportation affects the environment due to high emissions, with airplanes and trucks generating particularly high levels of carbon dioxide emissions. Therefore, these were deemed bad for the environment, while the use of ships was seen as a better alternative. The students also proposed additional solutions, such as producing goods closer to consumers to reduce emissions and using trains or other electric vehicles for transportation to minimise environmental impact.

When discussing production, the students said that it contributes to climate change and that products manufactured in Sweden are more environmentally friendly. They also highlighted concerns regarding the use of raw materials, with one student pointing out that we use resources and raw material that we do not have. Which reflects the concern that we are consuming raw materials at a rate that exceeds what is sustainable and available.

The Economic Dimension

When students talked about the economic dimension, they focused on transportation and usage & retail. They noted that buying frenzies, driven by frequent sales like Black Friday, Singles’ Day, and Cyber Monday, lead us to purchase more than we need. They also noted that constant new trends and extensive marketing, especially on social media, unconsciously influences us to buy more. In comparing online shopping to in-stores shopping, they mentioned that while online shopping is often cheaper, it may also come with potential quality issues. Shopping from Swedish websites was viewed as a preferable option.

Regarding transportation, the students stated that boats and airplanes are the two most common modes of transport. They noted that while both are efficient, they have distinct advantages and disadvantages. Flights were considered fast but expensive, while boats are time-consuming and fuel-intensive, yet capable of transporting large quantities of goods. One student suggested improving the efficiency of cotton transport by processing cotton on the farms themselves and have facility and warehouses in each country. She explained that this would reduce transport distances with lower costs and emissions, but also save time.

Regarding production, the students talked about how companies profit by exploiting cheap labour to minimize production costs and then selling products at higher prices abroad. One student suggested reinvesting profits to increase farm productivity and efficiency, which would increase earnings for the country and ultimately improve workers' wages and conditions.

When students talked about disposal, the conversation focused on the resale of goods. The students stated that surplus food and second-hand items can be sold at lower prices. Thus, they considered second-hand items more affordable.

How are these dimensions connected in the students' conversations?

The results show that when the students talk about the product life cycle, they express connections to each dimension of sustainable development. However, they also establish connections between the dimensions, and through the analysis three themes were constructed: The Dimensions are Isolated, The Dimensions Harmonise, and The Dimensions are Contrasted.

The Dimensions are Isolated

In the students' conversations, the dimensions sometimes appear isolated from each other, meaning that the students talk only from one perspective of sustainable development. This is particularly prominent when they talk about the social dimension in relation to production. In Excerpt C, the students Nina and Alex can be seen speaking about poison and working conditions.

Excerpt C

Nina	There are also a number of toxins in the production process. and the workers get sick from it and don't get the best care, so it's kind of horrible. …
Alex	In many cases it is also ... it can be really dangerous environments they work in. Poisons and so on are very often used, and it is allowed in many countries to use life-threatening pesticides and so on, where many people die or are seriously injured.

They emphasise that issues related to workers' health arise when companies use poison in their production, which relates to the social dimension of sustainable development. However, they do not establish connections to, for example, the ecological dimension and how the same toxic chemical affects ecosystems and non-human species.

The Dimensions Harmonise

The students express that the economic and ecological dimensions harmonise when they talk about transportation and disposal. In the example below, Jane states that reducing transportation distances could simultaneously decrease emissions and lower fuel costs (see Excerpt D).

Excerpt D

Jane	These are a lot of unnecessary transport distances, and it would be possible to eliminate many thousands of kilometres and thus reduce emissions, simply by reorganising a little, and everyone would benefit in the long run because there would be lower fuel costs.

Furthermore, when they talked about disposal, they also consider both the economic and ecological dimensions. They express that reusing resources, such as second-hand is both cost-effective and climate friendly.

In one group, students discussed the use of pesticides in production from both the ecological and social dimension. They stated that pesticide spraying affects biodiversity and causes animals and plants to die. They further pointed out that the chemicals eventually end up in lakes, streams, and groundwater, highlighting that spraying crops impacts humans as well, who then drink the contaminated water and eat the sprayed food.

The Dimensions are Contrasted

The dimensions are primarily contrasted when the students talked about production and usage & retail. The economic and social dimensions are contrasted when discussion production and companies' economic growth. The students stated that companies use cheap labour, often in poor working conditions and child labour, to maximise their profits.

When conversing about usage & retail, the students contrasted the tension between economic and ecological dimensions, particular when purchasing cheaper products at the expense of environmental considerations. They also pointed out how companies use marketing strategies, such as claims of reduced environmental impact, in order to get people to buy more (see Excerpt E).

Excerpt E

Nina	Yes, but companies do carbon offset, but really it's like this: just because you grow a tree, you don't carbon offset.
Jane	No, it almost feels more like a sales trick that: we carbon offset because then consumers will feel: yes, but we can buy more, it's okay they have carbon offset because I bought their sweater.
Nina	Yes, and they say we are carbon offsetting, yes but we are planting some trees.
Jane	But how do you carbon offset? Are you going to go out and capture carbon dioxide with a net - that will be difficult? There will be a climate impact.
Nina	Yes and many people who carbon offset they might buy a big piece of land in Africa of all places and plant trees there.
Jane	Yes, and there is no certainty that they will do that either.

Alice	If they say that, they might do it but it could also mean that we are carbon offsetting and that means that they plant 10 trees in a year which is an extremely minimal carbon offset.
Alex	It doesn't say exactly what kind of trees they plant, not how many trees they plant or where they plant.
Nina	Yes, and then maybe they take land from people in other poor countries.
Jane	Yeah, they kind of buy it from the state and then that affects people who live there - so it's not necessarily positive.
Nina	Yes exactly

What views can be traced in students' conversations about the product life cycle?

From the thematic analysis, the students' views on sustainability were traced. From this, two themes were constructed.

Technology for sustainable development

The students generally exhibit a strong belief in the potential of technology to solve environmental problems, particularly evident when the students talked about transforming the transport system. They highlight electric cars, trucks, and trains as solutions to reduce or eliminate carbon dioxide emissions. In one conversation, the students discussed among themselves whether online or in-store purchases are better. They reached the conclusion that both have an impact on the environment and lead to emissions. However, the student James suggests that if transportation is electric, it does not affect the environment (see Excerpt F), and his statement remains unopposed.

Excerpt F

James	It depends on what kind of transportation you use. If you travel by train or electric car, it does not affect the environment

Sustainable development for humankind

Students related the product life cycle to environmental impacts with statements like "it destroys biodiversity", "it is bad for the environment", and "we should not waste Earth's resources". These statements are somewhat ambiguous in terms of their views. As their conversation continued, they sometimes explain why these environmental impacts are negative, often referencing how they ultimately affect humans. For example, they talked about pesticide spraying, water scarcity, and reduced biodiversity, noting how these issues would affect people's living conditions. One group talked about that spraying crop affects biodiversity (see Excerpt G). Student Liam states that biodiversity is important because it affects plants and animals. In the next statement, there are traces of an anthropocentric view as he states that ultimately humans will not be able to breathe. Olivia continues by pointing out that the spraying contaminates groundwater, which we drink, and emphasises caution, especially when spraying food that we will eat. In the conversations, the impact on humans is often the concluding point.

Excerpt G

Liam	But organic stuff is good
Ava	Yes, it's better anyway

Liam	But it's also more expensive. You also have to think that not everyone can pay for everything.
Ava	No, and then you have to make sure that the majority of all food production is organic, so maybe it will be a little cheaper. Or that the state goes in and subsidizes or something you have to do something anyway.
Olivia	Yes, to promote more climate-friendly. So if you constantly spray ... plants and crops and so on, then, then these chemicals will end up somewhere else eventually, for example in lakes or rivers or in the sea
Liam	Yes, but then this spraying also affects biodiversity, which is very important for the environment that biodiversity works because otherwise plants and animals would start to die out and eventually we will not be able to breathe as well.
Olivia	The spraying ends up in the groundwater and that groundwater... So we use that groundwater. We drink that groundwater. So spraying too much is not good. To a certain extent, it may be necessary in some situations, but you should probably be very careful about where and how you spray, especially food, which we also eat.

Water appears in further examples where an anthropocentric view can be traced. When students talked about how the cotton production leads to water shortages, they explain why this is bad based on the impact on people's living conditions. The impact of water shortage on other species is not mentioned in the students' statements. Thus, an anthropocentric view can be traced even in these conversations.

Discussion

In this study, we provide insights into secondary school students' conversations about product life cycles in relation to sustainable development. The findings show that the participating students talk about different parts of the product life cycle to varying degrees linked to the sustainability dimensions (research question (i)). When the students talked about the social dimension of sustainable development, they primarily considered the production of goods. While, when they talked about the economic dimension the students mainly talked in connection to usage and retail as well as transportation. However, when the conversation revolved around the ecological dimension, students talked in relation to all phases of products' life cycle.

But the dimensions of sustainability interact and influence each other within technological systems and exploring these inherent tensions and complexities should be a part of technology education in line for education for sustainable development. Emphasising a comprehensive and pluralistic approach and highlighting the interconnections between the dimensions is essential (Berglund and Gericke, 2016). We saw a need for a deeper exploration of how students´ combined or contradict the sustainability dimensions.

In Öhman & Öhman's (2012) study, students did not address conflicts of interest and tended to perceive the dimension as harmonising with each other. In contrast, the students in this study not only talked about how the dimensions interact harmoniously but also highlighted the conflicts of interest that can arise between them (research question (ii)). This mirrors the relationship between sustainable development and the product life cycle which is full of contradictory objectives. Examining these interactions provides a deeper understanding of both the challenges and opportunities involved in achieving sustainable development (Herremans &

Reid, 2003; Sterneäng & Lundholm, 2012). Viewing sustainability issues from multiple dimensions and understanding the interactions between and within systems is known as systems thinking, a key competence among the twelve preferred in GreenComp (Bianchi et al., 2022).

The GreenComp competences emphasise the importance of explaining and critically evaluating different views on sustainability. This involves reflecting on one's own view and being aware of various approaches to sustainability. These moral and philosophical views influence different assumptions and arguments presented (Bianchi et al., 2022). The results from research question (iii) show traces of viewpoints in these students´ conversations, the main findings were anthropocentric and technocentric. Although the ecological dimension was evident in their conversations about the entire product life cycle, indicating an awareness of the environmental impact from production and consumption, their viewpoints were anthropocentric and technocentric. Bianchi et al. (2022) emphasise that students should be encouraged to act responsibility and with care for our planet both now and in the future. The sustainability competences stress the importance of showing empathy toward all form of life. It is crucial to recognise that all living organisms and non-living elements are closely interconnected and interdependent, with humans being an integral part of nature rather than superior to it.

Limitations

In this study we wanted to provide insights into secondary school students conversation related to sustainable development. But in a study where students engage in group dialogue, it is difficult to get a comprehensive picture of students' thoughts and opinions. Some students may be more inclined to speak than others, which may lead to some voices dominating the discussion while others remain silent. This can affect the diversity of expressions that emerge from the dialogue. Additionally, the aim of this study is not generalisability, but rather to describe what emerges in the students' conversations. Both these matters have been considered in presentations of the findings. Furthermore, within the group interviews, students are assumed to be influenced by group dynamics or social norms. Therefore, what they express is not interpreted as perceptions of students but rather what they want to convey in this context. Nevertheless, such expressions and these group discussions provide valuable insights for technology education.

Implication for practice

These findings offer valuable implications for technology education, both in term of content and practice. Educators can leverage this understanding of how students discuss sustainable development and product life cycles to refine and enhance technology education curricula and teaching methods. Notably, the findings provide insights into specific dimensions of sustainability within the product life cycle that can be further emphasised in technology education. This to achieve a holistic perspective of sustainable development with a pluralistic approach that also highlights the interconnections between economic, ecological, and social dimensions (Berglund & Gericke, 2016).

In line with the pluralistic approach, it is crucial to understand diverse views on sustainable development, not to impose specific values on learners, but to illustrate that values are constructs and that we can choose which values we want to prioritize (Bianchi et al., 2022). The method used in this study generated interesting discussions where perceptions, emotions, and values linked to sustainable development appeared. Similar classroom discussions as deliberative conversations can be part of technology education to initiate dialogues where students can learn from one another (Gustavsson and Warner, 2008). These conversations increase awareness of sustainability´s complexity, promote critical thinking, and help develop the skills necessary for making informed, sustainable decisions – ultimately leading to greater student action competence.

Technology education must equip students with the knowledge and skills needed to develop a responsibility toward both the current world and for the future. Integrating sustainability into the teaching of product life cycle creates a valuable opportunity to educate informed, conscious citizens who can drive positive change in technology development. As highlighted by Elshof (2009), Pavlova (2013), and Stables & Keirl (2015), technology education plays a crucial role in fostering a new perspective on how we use, consume and design technology with an emphasis on social, economic and ecological sustainability. Empowering students with a sense of responsibility will enable them to actively contribute to a more sustainable world.

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Collage as a Reflective Tool: Teachers' Perspectives on Forests and Urban Environments

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Abstract
The study aims at professional development directed towards finding new pathways in education for and in sustainable development. In this study, we consider how primary teachers from two schools in Gothenburg, Sweden, experience the forest and the urban area as potential learning environments. This study focuses on teachers' perceptions (understanding) and experiences (emotional) of two places, the urban area, and the forest. To make visible teachers' relationships with the urban area and the forest, we use collage inquiry as a research method to stimulate teachers' reflection, conversation and writing about the forest and urban area. Primary teachers from three schools in Sweden participated in the study and made collages The collage inquiry brought out their emotions, perspectives, and curiosity about the forest and the urban area described in three themes*; temporarily situated*, *place dependent* and *emotionally connected*. Knowledge of teachers' perceptions and experiences ensures opportunities to deepen the ability to teach technology beyond the classroom. To bridge between biology and technology and compare ecological and technological systems constitutes a possible basis for continued work and development of teaching for sustainable development.

Keywords
Ecological literacy, technological literacy, collage inquiry, practice-based research.

Introduction
Teachers' perceptions and experiences of how technological systems and ecological systems are structured, and function have significance for how they tackle sustainability issues in the classroom. The study presented in this paper is part of a collaborative practice-based research project (Svensson, Sanders, & Thorén Williams, 2022) aiming at finding new paths in education for sustainable development through school subjects, technology, and biology. In the project, biomimicry forms a bridge between knowledge of the ecological systems in the forest and how these systems can be imitated in human-made technological systems in an urban environment for increased sustainability. The urbanisation of society indicates that the distance between people living in urban environments and nature is increasing. Reflection is viewed as one of the powerful ways for teachers to develop their knowledge (Dillon, 2011) and a sense of being able to handle teaching subject content in relation to sustainability issues in the classroom. In this study, we explore an art-based method to stimulate reflection. The method, which is inspired by Butler-Kisber's (2010) chapter in Qualitative Inquiry: Thematic, narrative and arts-based perspectives and is called 'Collage inquiry'. The purpose is on the one hand to the mapping of teachers' perceptions and experiences of nature and urban environments, and on the other hand, to evaluate the potential of the collage inquiry as a tool for stimulating reflection and making different perspectives visible.

The teachers’ perceptions and experiences of the forest and the urban area, lay the ground for their bridging of the two environments to address sustainability issues on a system level in the classroom. In this paper, we make a distinction between perceiving and experiencing something. Perceiving connects to how we think and what we understand while experiencing relates to emotions and senses. Concerning our purposes, these research questions are identified:

- What perceptions and experiences of the urban area and the forest appear in the collage inquiry?
- In what ways does the collage inquiry make visible teachers' relationships with the urban area and the forest?

Background

Practice-based research is of relevance for education and pedagogy, aiming at schools’ development and conducted by researchers and teachers in collaboration (Nilholm, 2020). Persson (2020) highlights the importance of being careful as researchers, in practical research projects to be able to switch between the necessary closeness and familiarity that one needs to have about the practice one is studying, and at the same time to have a scientific and professional distance. It is therefore important to see practical research as a development of knowledge where one presupposes the other. The current study takes its point of departure in a practice-based research project where primary school teachers together with science centre educators and a research group, learn about how we relate to the forest and the urban area personally and professionally in different ways.

The small forests near the schools are places where primary school teachers regularly go with their students to play and learn about animals and plants. The nearby urban areas are, in contrast to the forest, areas which are not related in the same way (Szczepanski, 2013). Urban areas are human-constructed worlds with various artefacts and technological systems that have the purpose of meeting human needs. In this project, both the urban area and the forest are essential places, for bridging between technology and biology teaching, where the forest ecosystem(s) with its organisms can inspire and challenge teachers’ and their students' thinking about how to design sustainable technological systems.

Students' understanding of technology's importance to and impact on people, society and the environment is emphasised in the Swedish National Curriculum (Skolverket, 2022). According to this curriculum, technology education should develop the students' technological awareness and ability to relate technological solutions and their use of technology to issues related to sustainable development. By making technological solutions visible and comprehensible in teaching, students are given the conditions to orient themselves and act in a technology-intensive world. In recent years, several researchers (Ingerman & Collier-Reed, 2011; Svensson, 2011) have referred to this type of knowledge or generic skills as technological literacy. Technology is about developing and designing new artefacts and systems to change and improve our surroundings. There is a downside to the human drive to constantly develop and change artefacts and systems if consideration is not given to the global and environmental impact of this development. According to McCormick (2006) and Keirl (2006) technology literacy is also about enabling students to reflect on their technological lives, to develop critical awareness about how to live in a technological world, and to learn to discern the benefits and disadvantages of technology. Therefore, it is of great importance to include sustainability perspectives in design work to find new sustainable ways to develop technological solutions (Pavlova, 2013). In this regard, we find Ingerman and Collier-Reeds (2010) model of technological literacy useful where two interrelated perspectives are fundamental elements of the concept of literacy, the potential for technological literacy and the enactment of technological literacy. The potential is made up of knowledge about a particular situation, personal engagement with a situation, and social engagement with the world. Enactment requires a particular set of skills in action, which together help to shape the situation: recognising needs, articulating problems, contributing to the technological process, and analysing consequences.

As societies progress and become more technologically advanced, there is a noticeable decline in the general population's understanding of ecological systems and their importance to human survival and well-being. This knowledge gap not only hinders effective policy-making and personal decision-making but also exacerbates the disconnect between humans and the natural world. The pursuit of ecological literacy, as explored in the works of Lisberg Jensen (2016), McBride et al. (2013), and Magntorn (2015), highlights a critical educational endeavour necessary for fostering an environmentally aware society. Lisberg Jensens (2016) discusses the diminishing ecological literacy in modern societies, identifying a growing disconnect from nature due to more abstract and less experiential educational approaches. This ecological illiteracy, Lisberg Jensen (2016) argues, obscures our ability to effectively engage with and respond to environmental challenges. According to McBride et al. (2013), ecological literacy is described as the understanding of ecological systems through scientific inquiry and systems thinking. It pertains to the comprehension of the relationships and functions within ecosystems, stressing the biological and scientific aspects of environmental interactions. Magntorn (2015), focuses on the concept of "reading nature," an ability to recognize organisms within their ecosystems, understanding their roles and interactions with other organisms and the environment. This ability to identify parts and their function within a system is an essential component of ecological literacy. All three sources advocate for a transformative educational framework that goes beyond traditional learning to include direct experience and interaction with the natural world, aiming to cultivate a deep-seated ecological consciousness among individuals.

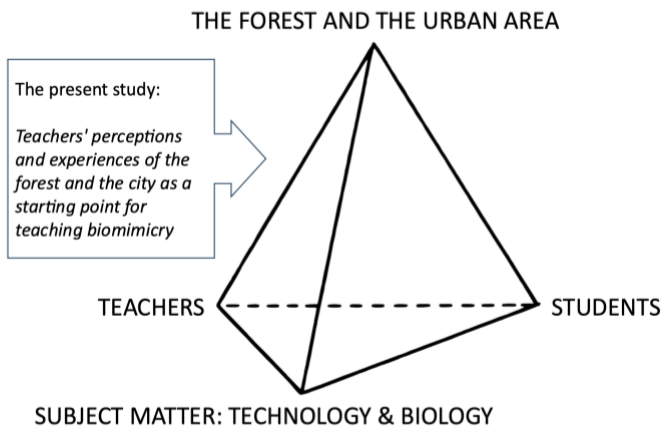
In this research project, the overall purpose is to explore teachers' perceptions and experiences of technological systems in the urban area and ecological systems in the forest, to prepare them for teaching about sustainability issues. We want them to focus on the two situations/contexts, which are different but similar in terms of the systems perspective and the need for systems thinking to understand the situations. We see systems thinking as an aspect of technological and ecological literacy. Using the technological literacy model (Ingerman & Collier-Reed, 2010) allows us to describe the potential of both ecological and technological literacy and to find traces of knowledge, and personal and social engagement with systems in the forest and the urban area.

The didactic tetrahedron

To contextualize the present article within the broader scope of the practice-based research project, it is pertinent to employ the didactic tetrahedron model, initially proposed by Rezat and Sträßer (2012) and subsequently adapted by Nyman (2017) and further by Thorén Williams

(2021). This model provides a comprehensive framework for understanding the interrelationships between the teacher, students and the subject matter engaged within a didactic situation and the interrelationships within the research project. Brousseau and Balacheff (1997) conceptualize didactical situations as instructional contexts that facilitate student engagement with the subject matter, a concept further illustrated by the didactic triangle framework (Rezat & Sträßer, 2012). In these situations, the actions of the teacher cannot be comprehensively understood without a concurrent understanding of the student's actions and the structured knowledge of the subject matter. This interrelation forms an indivisible system characterized by the didactical triangle, which includes the teacher, student, and subject matter. The dynamics within this triangle are perceived holistically, wherein each component influences and is influenced by the others. Rezat and Sträßer (2012) extend this model by introducing a fourth vertex, representing the environment's material resources, thereby acknowledging their role and impact within the didactical situation. This addition enhances the model's capacity to account for external influences such as a physical environment on the teaching-learning process (Thorén Williams, 2021)

Within this framework, the present article is elucidated and aligned with the 'Teachers – The forest and the urban area relationship, as depicted in Figure 1. This model thereby serves both as a structural foundation for the overarching research project and as a guiding didactic framework for each constituent study.



Figure, 1. The figure illustrates how each of the four studies relates to the areas of the didactic tetrahedron (Author, 2021), adapted by Nyman (2017) and initially developed by (Rezat & Sträßer, 2012).

Method

Art-based research methods are highlighted as valuable for their ability to unlock novel insights and foster more equitable researcher-participant relationships. However, art-based methods which consist of a palette of techniques, encompassing creativity, visualisations, and performative approaches, have only been marginally incorporated in science education research (Hoppe & Holmegaard, 2022). In their literature review, Hoppe and Holmegaard (2022) discern four central themes that underscore the unique advantages of art-based methods, 1) non-verbal language; facilitating a broader range of expression, allowing participants to convey meanings that might be difficult to articulate verbally, 2) power and positions; altering traditional power dynamics in research settings, offering participants a more active role in the knowledge creation process, 3) knowledge through artefacts; where artefacts act as mediators in the research process, helping access deep-seated memories and meanings, thus enriching the understanding of the participant's world, and 4) time for reflections; providing a slower, more reflective pace of interaction, which is crucial for deeper engagement with the research topic. One example of using collage inquiry as an art-based method in science education is Awan (2007). In her study, young people aged 13 to 14 were invited to create identity collages using media materials. The collages, along with accompanying reflective commentaries, formed a valuable dataset for the study. Similar to Awan's (2007) study, data in the form of collages together with teachers' discussions and descriptive texts constitute valuable data in this paper. However, in this study, teachers are asked to reflect on their relationships to phenomena in the world, both personally and professionally.

Butler-Kisber (2010) explores the use of collage, specifically employing found images from popular magazines, as a tool for reflection, elicitation, and conceptualization. Elicitation involves drawing out a variety of perceptions, interpretations, and possibilities. We agree with Butler-Kisber & Poldma (2010) that the visual approach such as "making a collage is not daunting because everyone, whether a novice or veteran, can cut and paste and ultimately gets a sense of satisfaction with the product" (p. 5). Collage inquiry is a user-friendly art method that leverages basic skills like cutting and sticking, familiar from early childhood (Butler-Kisber, 2010). The collage inquiry is thus chosen with regard to the teachers' and researchers' familiarity with creating collages. Furthermore, collage inquiry sets out a specific 'angle of arrival' (Allsop & Dillon, 2018) to engage the participants to reflect upon the forest and the urban areas. Making the collage involves selection, wanting to choose a specific kind of representation and the option to add words and symbols. In creating the collages, the teachers' relations to the urban area and the forest emerge (Butler-Kisber, 2010). In addition to mapping teachers' perceptions and experiences of the forest and urban area, making a collage can afford affective elements such as emotions and attitudes. The collage inquiry used in the current study takes inspiration from Butler-Kisber's (2010) "Collage Inquiry". Although collage inquiry can unlock novel insights, Hoppe and Holmegaard (2022) emphasize the need for sensitivity towards the participants' backgrounds and capabilities in art-based methods. Researchers must be cautious of potential power imbalances and ensure an inclusive, respectful approach to participant engagement. therefore, the researchers also participated in collage creation together with the participating teachers.

In the collage inquiry, fragments from materials such as magazines, and coloured paper of various kinds of yarn and fabric were used to visualise perceptions and experiences of forests and urban areas. The cut-outs that we take from magazines and other materials and put together in a collage provide a tool that allows for expressing and communicating phenomena in a more diversified way. The collage inquiry works here as a tool to stimulate reflection (Hoppe & Holmegaard, 2022) and broaden perspectives and conversations about the forest and the urban area. The collages constitute visual documents within the practice-based research project of which this study is a part (Butler-Kisber, 2010).

Participants

The two schools participating in this study reached out to researchers in teacher education to collaborate around teachers' professional development concerning sustainability. This interest initiated a practice-based research project. Seven teachers from the three primary schools in

Gothenburg (see Table 1), and three researchers participated in the collage inquiry workshops. All three primary schools (students of ages 6-12) were diverse schools with teachers and students with Swedish as an additional language.

Table 1. A demographic overview of participating teachers (assigned pseudonyms).

Schools	Participating teachers	Demographic characteristics
A	John and Veronica	Upper primary school teachers (students ages 10-12). Teach Mathematics, technology and science.
B	Anna and Cecilia	Lower primary teachers (students ages 6-9). Class teachers with eligibility to teach Swedish, mathematics, English, social studies, history, religion, geography as well as natural science and technology.
C	Salma and Eva	Lower primary teachers (students ages 6-9). Class teachers with eligibility to teach Swedish, mathematics, English, social studies, history, religion, geography as well as natural science and technology.
	Annefrid	Preschool/preschool class teacher, has training in Children's communication and language; Children's Mathematical Learning; Play, learning, development and care; Collaboration with guardians, preschool class, after-school centre and school; Aesthetic learning processes; Nature, environment and technology

The data consists of the collection of photos of the teachers' collages, teachers' descriptions of collages, teachers' interpretations of each other's collages on post-it notes and transcriptions of video- and audio recordings of the collage workshops. The transcribed data is from the part of the workshop when all the collages have been completed and after everyone in the group has taken part in the others' collages and with a few words or sentences (on three separate post-it notes for each collage apart from their own) wrote down his interpretation of the collage.

The Approach to the Collage Inquiry Workshop

The group of teachers were divided into two workshops, three teachers in the first one and four teachers in the second workshop. We as researchers participated in both workshops. Each workshop occasion took about two and a half hours. Before we started making collages, the researchers prompted these questions: What are your perceptions of the urban area and the forest? What are your experiences of the forest and the urban area? In addition, everyone was instructed to use the materials (magazines, paper, fabric, and yarn) that were presented to make a collage that represents one's perceptions and experiences of these environments.

The work with the collage took about 45 min up to an hour for everyone. Then about 20 minutes were devoted to writing a paragraph about one's collage and giving it a title. After a 15-minute break for refreshments, we all looked at each other's work and, on each collage, everyone had to write down their short interpretations of the collages on three separate post-it notes for each collage apart from one's own. These interpretations could be sentences or words. The Post-it notes were then attached to the back of the collages.

After this step, we all gathered around a large table to present the collages to each other. The presentation followed a given order, where everyone in turn read out the title of their collage and then their descriptive paragraph. Not everyone had time to write a paragraph during the workshop but submitted one later. The participant who presented his or her collage then had to turn the collage with the back facing up and read aloud what was written on the post-it notes attached. An important part of this step was affording the collage owner to comment and reflect on the other participants' interpretations and perspectives. After everyone presented their collages, a discussion followed about the different interpretations and perspectives of forests and urban areas.

Analysis

The transcriptions of video, recordings and collage descriptions were analysed through thematic analysis (Braun & Clarke, 2006). In this process, the three researchers' collages, descriptions and presentations were excluded from the data material. Pictures of the collage together with the teachers' written descriptions and the transcribed presentations and discussions were read and reread by all three researchers to code and find themes across data that described what perceptions and experiences of the two places, the urban area, and the forest, were in the foreground of teachers' reflections in all three sources. The thematic analysis largely followed the process described in Riger and Sigurvinsdottir (2016) with some exceptions. For example, this study carried out a more theory-driven analysis (Braun & Clark, 2006), which meant that the three senior researchers had the research questions in mind during the analytical process. This study's data material consisted of transcriptions of the teachers' presentations of their collages, subsequent discussions and the teachers' descriptive texts. It was therefore important to ensure that coding and themes were valid across the entire data material. The teachers' collage descriptive texts were critical in the analysis as they constituted teachers' more detailed descriptions of perceptions and experiences of the forest and the urban area. Thus, the texts could confirm or contest the researchers' interpretations of the transcriptions. The emerging themes were evaluated through discussion between the three authors and with research colleagues at the PATT40 Liverpool 2023 conference (Thorén Williams, Svensson & Sanders, 2023) to describe the special nature of the themes. To deepen the understanding of the three themes, the model of technological literacy (Ingerman & Collier-Reed, 2010) was used to describe the potential of ecological and technological literacy as knowledge, personal and social engagement.

Results

The collage inquiry as a method makes visible not only teachers' perceptions and experiences but also their professional identity and personal/private identity concerning the urban area and the forest. The collage inquiry brought out emotions, perspectives, and curiosity, which are powerful tools in teaching and engaging students. Three themes, temporarily situated, place dependent and emotionally connected emerged in the analysis which describes the character of the teachers' reflections that came into their foreground about their perceptions of the forest and the urban area and their experiences of these places.

Temporarily Situated

In this theme, the teachers are reflecting on the places by looking into the future and/or looking back on history, focusing on humans living close to nature and then moving into cities, becoming more separated from nature. The problems that we see in the urban area today need to be solved sustainably in the future. John presents his collage and points at the picture (Figure 2) of a child.

Figure, 2. John's collage

> *It is a child who symbolizes the future and who looks up with the hope that it will be even better and more sustainable in the future... at the same time there is a man in fur who reminds us of the old days when the cities were dirty and smelled bad because they lacked knowledge about sustainable living, hygiene and how to build, choose materials and plan....all people and residents have their primary needs, instincts, but all problems need to be solved... in the cities.*

Veronica describes her experiences and understanding of the two environments:

> *Once upon a time people thought it was great fun to live in cities and this is [points to an image in the collage] the image from the nomads' what is it called, tents that they left in a pile and then they move to the city and very quickly you discover that you need - we have always had the forest in our homes. An example is the Christmas tree, which we go to the forest to get when we celebrate Christmas and so on and so forth...*

The teachers have chosen pictures that represent the future in the urban areas, spaceship and modern buildings, and the forest as a Christmas tree or a green area between buildings and the past with pictures of tents and forests. This reflects their feelings and understanding of a change in society as well in nature. We also interpret this as an understanding of the effects that technological development can have on nature and society over time, both in making life easier for humans and causing problems regarding sustainability.

Place Dependent

The teachers describe their relations to the forest and the urban area by highlighting things to see and do. There are also traces of limitations of the places. In the forest, you can play as a child but in the urban area, you are not allowed to move around as you want to. The two places invite to and afford certain activities and can thus be seen as complementary and integrated.

Figure, 3. Anna's collage.

> ***Anna**: When I think of the city, I think of people. Lots of people gathered in one place. Everyone needs somewhere to live, employment, to get to different places by car, bus, tram, etc.[...] In the forest, there is calm, peace, nature, soothing scents, moisture after the rain, the sun shining through the trees, a cup of hot chocolate. Good clothes and shoes. Child playing, climbing, running, exploring. Mushrooms, berries, ghost walk, animals, insects. Light, darkness.*
>
> ***Cecilia**: My experience of the forest is the silence and at the same time the life of the forest. I also often experience the forest/nature within the city, such as in gardens, farms, forest groves in the city. It shows humans' need and desire to be close to nature, even in the middle of the city [...] my understanding of the city is that it should be accessible, efficient, convenient for people who live there. Water, heating, communication, payment system, sewage, infrastructure (bridges, roads) everything must work. My experience of the city is instead about religion, culture, art, education, and other values found in the city. (The kind that I don't get access to in the forest).*

The teachers' experiences of the forest are depicted in pictures that show when and why "I visit the forest": picking berries and fruit, resting, and exercising, cycling, jogging, and walking the dog. The experience of the forest is the silence and at the same time the life of the forest. They also often experience the forest/nature within the city, such as in gardens, farms, and forest groves in the city. This indicates that people need and want to be close to nature, even in the middle of the city. Their perception of the city is more about religion, culture, art, education, and other values found in the city. Something they don't have access to in the forest.

The teachers' perception of the forest is instead about the ecosystems that prevail there, hierarchies in the forest, and how tough the forest is for those who live there. It is about the survival of the fittest, but also the adaptability of the forest and the animals. Perceptions of the forest are also how we humans affect the forest through logging, fossil fuels, cultivation, etc. Their perception of the city is that it should be accessible, efficient, and comfortable for the people who live there, water, heat, communication, payment system sewage, infrastructure (bridges, roads) and everything should work. There is a personal engagement in both the technologically intensive urban area and the non-technological forest which we interpret as a sign of potential technological and ecological literacy.

Emotionally Connected

The theme describes teachers' emotional connections to the forest and the urban area. Their feelings about the urban area have a more negative character, i.e., stress, high noise level, and disorder, but there are also traces of friendship and belonging. The forest, on the other hand, brings out emotions such as calm, silence and order, and light but here too there are negative feelings such as darkness, fear, and uncertainty.

> ***Eva**: I listen to the forest outwardly, both for sounds that fill me with well-being and also for sounds that can warn me of danger. In the forest there is peace and quiet but also anxiety. Some of my biggest fears live in the woods – spiders, moose, and wild boar. In the city, I listen inwardly, do what I want to do, spend time with friends and family, go to the gym and exercise [...] But there is also anxiety in the city, anxiety about having an accident - maybe getting hit by a car -, anxiety about running into people who want you badly.*

Figure, 4. Eva's collage

Our interpretation of this is that the images that the teachers choose when they make their collages bring out emotions that might otherwise be difficult to access. The pictures act as mediators in the process, helping access memories and meanings and in that way enriching the understanding of how the teachers experience the forest and the urban area.

Discussion

With the collage inquiry, different interpretations and perspectives were made visible (Butler-Kisber, 2010). The collage inquiry stimulated reflections and discussions about personal as well as professional relationships with the forests and urban areas. Coming together as teachers and researchers, reflecting, and sharing ideas through the making of collages, contributed to self-awareness and a sense of community. The commitment and creativity that arose allowed reflections, without the teachers exchanging any words during the collage work. Finding images, cutting, composing, and pasting images required concentration. The desire to find a particular image, symbol or word was a purposeful endeavour. It was noticeable how the making of the collage slowed down the pace of interaction, allowing one to reflect on one's relationships with the forests and urban areas. The making of collages also brought out emotions in ways that we did not expect. The three themes; *temporarily situated*, *place dependent* and *emotionally connected* indicate that collage inquiry encompasses several dimensions, including teachers' relationships to history, situation and identity. Awareness of these dimensions is critical to teach complex issues of sustainability in technology and biology.

The making of collages enabled a wider spectrum of expressive possibilities, permitting teachers and researchers to communicate meanings that could be challenging to express through verbal articulation alone (Hoppe and Holmegaard, 2015). During each and everyone's presentation of the finalized collages, it became evident that these compositions served as a significant facilitative medium for narrating perceptions and experiences. The writing of paragraphs and the assignment of titles to the collages were activities that most of the teachers undertook after the collage creation. It exemplifies how the collages functioned as mediators in the writing process, facilitating the elicitation of deeply entrenched memories and meanings, thereby enhancing the comprehension of the participating teachers' perceptions and experiences (Hoppe and Holmegaard, 2015). However, writing came easier to some of the participants than to others, which further enhanced the power of the collage inquiry for stimulating reflection and discussion in the teacher-researcher group. The active role of the teachers is an important prerequisite in the practice-based project as a whole.

Different aspects of the teachers' personal relationship to the two environments, the urban area and the forest, and their understanding of the relationship between the two emerged during the collage inquiry, but also aspects related to the society were discernible. This indicates a system thinking approach, seeing parts and connecting them, which are essential for understanding sustainability issues, and thus part of technological and ecological literacy. Similar to what is described by Ingerman and Collier-Reed's (2010) in their model of a potential for literacy, personal and social engagement are two dimensions that in this study are salient. Traces of the knowledge dimension were present, however, emotional connections to the environments constitute a first step towards technological and ecological literacy.

Knowledge of teachers' perceptions and experiences ensures opportunities to deepen the ability to teach beyond the classroom and to reflect on that teaching. From a teaching and learning perspective, this relates to one of the surfaces of the didactic tetrahedron (Thorén Williams, 2021): the teacher – the forest and the urban areas - the subject matter (the technological and ecological systems). The teachers' relationships to the two environments, visualised through collage inquiry raise teachers' awareness about the technological and natural world. Using a system thinking in discerning the benefits and disadvantages of the two worlds is critical in sustainability education to find new ways to develop technological solutions. In the continued work of teaching for sustainability, we believe biomimicry has the potential to support this development and bridging between biological systems and technological systems.

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29.2

Empowering Student Teachers to teach Technology with a sustainability edge: Crucial aspects to address in Teacher Education

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Abstract

Technology education in primary schools must integrate sustainable development to provide young learners with the basic knowledge, skills, and values to understand, appreciate and contribute to a sustainable future. This integration prepares them for the challenges of a rapidly changing world, promotes responsible use of technology and fosters a sense of environmental responsibility from an early age. However, for this to happen, teacher education needs to adopt strategies that empower student teachers to seamlessly integrate sustainable development into technology education and equip them with environmentally and socially responsible attitudes. The aim of this study is to explore what needs to be addressed in teacher education to prepare student teachers to teach technology integrated with sustainability. The study is part of a project where to develop a teaching module that will prepare student teachers to teach technology in primary schools, with special attention to how student teachers develop relationships between technology education and sustainable development. The study includes 12 student teachers enrolled in a science and technology course. Data were collected in several steps, including focus group interviews, and written individual reflections by student teachers. Based on thematic analysis, we identified what student teachers experience as crucial to being able to teach technology with a sustainability edge. The results show that preparing student teachers to teach technology with a sustainability edge requires a multifaceted approach that integrates knowledge of technology and sustainable development with personal values, pedagogical competence, critical thinking competency, and the adoption of transformative teaching practices.

Keywords

Technology education, Sustainable development, Teacher education, Student teachers, Primary school

Introduction

Technology education has an important role to play in developing pupils' understanding of the technology they encounter in their everyday lives. Today, technology education includes raising pupils' awareness of sustainability issues related to the use and design of technology. The integration of sustainable development in technology education is crucial for pupils as it equips them with future-oriented skills, environmental awareness, and ethical considerations. It promotes critical thinking, informed decision-making, and global citizenship, and prepares pupils to be the agents of change needed for a sustainable future (Leicht et al., 2018). Therefore, there is a need for education to reflect on pedagogies and strategies to equip pupils with sustainability knowledge to meet the promises and challenges of the future. However, a study by Dahl (2019), based on data from seven European countries, shows that teachers feel less prepared when it comes to teaching about sustainability and sustainable lifestyles. An important step in preventing such problems in technology education is to provide student teachers with both theoretical and practical knowledge of technology and to help them transform this into teaching technology in which sustainability is more explicitly integrated (Dahl, 2019; Pavlova, 2013; Pegalajar-Palomino et al., 2021). Further, research on student teachers' perspectives on teaching technology emphasises the need for a better understanding of how student teachers perceive the technology content they are expected to teach and suggests that teachers develop a significant portion of their subject matter knowledge during teacher education (see, for example, Courtney et al., 2017; Hallström & Klasander, 2017; McGlashan & Wells, 2013).

In a larger project, we are addressing these issues through a collaboration between teacher educators and a Municipal Technology Resource Facility (MTRF) that offers a variety of hands-on technology activities for pre-service teachers, in-service teachers, and other interested parties. The aim of the project is to develop a teaching module that can increase student teachers' competence in teaching technology with a sustainability edge, as well as to gain knowledge about what transformative processes are taking place, where expansion and development efforts can be more precisely designed in teacher education. In this project, we see the potential to both develop a teaching module that will provide high-quality training for student teachers and to contribute with research related to technology teacher education and education for sustainable development (ESD).

In this paper, we present a study carried out as part of the larger project. The aim of the study is to identify the aspects that student teachers experience as crucial to being able to teach technology with a sustainability edge. The results will contribute to knowledge of what needs to be addressed in teacher education to better prepare student teachers to integrate sustainability into technology education. The question guiding our research is: What aspects do student teachers experience as crucial to being able to teach technology with a sustainability edge?

Background

Technology Education and the Preparation of Future Technology Teachers

The Swedish compulsory education and teacher education are interrelated tasks, pupils are to be educated toward curriculum goals, and teachers must be prepared through teacher education to be the facilitators of learning for their pupils to achieve curriculum goals (Åstrand, 2023). Consequently, teacher education needs to present education that is in line with the school curriculum, as well as to prepare student teachers with relevant knowledge for them to be able to teach specific subjects.

The Swedish curriculum for the compulsory school includes technology as a mandatory subject for pupils in grades 1–9. In the curriculum, there is defined core content divided into three main areas: Technology, man, society and the environment; Technological solutions; and Working methods for developing technological solutions. These areas cover a broad content such as materials, construction, strength theory, electronics, programming, mechanics, technological development work and documentation, technological systems, the history of technology, and the consequences of technology for humans, society, and the environment (Curriculum for the compulsory, school, preschool class and school-age educare [Lgr 22], 2022). The abilities and knowledge that pupils are expected to develop are as follows:

- the ability to reflect on different choices of technological solutions, their consequences for the individual, society and the environment as well as how technology has changed over time.
- knowledge of technological solutions and how constituent parts work together to achieve appropriateness and function.
- the ability to carry out technology development work and construction work.

(Curriculum for the compulsory, school, preschool class and school-age educare [Lgr 22], 2022).

The teacher's approach to how technology teaching should be conducted has decisive importance for the extent to which pupils learn in and about technology. However, there is a great variation in technology teachers' understanding of what teaching technology implies in terms of purpose, subject content, and teaching methods (Norström, 2014). The Swedish School Inspectorate (Skolinspektionen, 2014) carried out a review of primary school teaching in technology. The report showed several shortcomings, such as teachers feeling unsure of what the content of the curriculum represents in terms of technological knowledge, as well as which approaches and methods characterise the subject of technology. Norström (2014) suggests that it is of utmost importance that technology teachers are able to interpret what the content in the syllabus of technology represents in terms of technological knowledge as well as in teaching methods, for being able to present high-quality technology education. Further, this is also important for providing an equivalent assessment and grading of pupils (Jones et al., 2013).

Teachers develop a significant proportion of their subject knowledge during teacher education (Courtney et al., 2017; Hallström & Klasander, 2017; McGlashan & Wells, 2013). That is, teacher education has an important purpose to guide and prepare future teachers on what and how to teach technology. However, the changing world is reshaping technology education, emphasising the need for up-to-date skills, fostering a global perspective, adapting to digital transformations, embracing interdisciplinary approaches, stressing soft skills, considering ethical implications, promoting inclusion and diversity, and integrating concepts of environmental sustainability. This place demands on teacher education to keep up to date and ensure that student teachers are equipped with the necessary knowledge and skills to teach technology. Teacher educators should not only focus on preparing student teachers with technological knowledge and skills but also on the ability to adapt to a rapidly evolving technological landscape and to contribute meaningfully to a complex world where education for sustainable development is at the forefront.

Transformations in Technology Teacher Education and ESD

In ESD it is highly relevant to ensure that all learners can contribute to global sustainability, in line with the global sustainable development goals (SDGs). However, the efforts made so far have not been sufficient (Dahl, 2019; Pegalajar-Palomino et al., 2021; UNESCO, 2017; 2018). The results of a systematic review by Pegalajar-Palomino et al. (2021) showed that teachers are less prepared, i.e. they lack the necessary professional competencies, to teach about sustainability and sustainable lifestyles.

There have been several calls within the research community for new and diverse ways of designing education (Bencze et al., 2020; Holbrook, 2009; O'Brien et al., 2013; Lönngren et al., 2021; Pavlova, 2013). Based on a review of how related strands of research in science and technology education (SAQ, SSI, and STSE) share commonalities, Bencze et al. (2020) promote contextual and holistic approaches. Hence, more authentic approaches in interaction with society. O'Brien and Sygna (2013) suggest the need for transformation in higher education from both the "outside-in" and the "inside-out", a revolution that "must be unconventional and bold" (p.57). Key competencies such as knowledge, skills ("what"), values, beliefs, and worldviews ("why") and pedagogical competencies ("how") need to be included in teacher preparation to facilitate the implementation of ESD. Similarly, Holbrook (2009) and Pavlova (2013) argue that transformations in teaching are crucial in science and technology education. Technology education can for instance equip individuals with problem-solving skills and foster innovation. This is critical to addressing sustainability challenges as it enables the development of creative solutions to environmental, social, and economic issues. This includes educating individuals about the impact of technology on the environment and promoting a holistic understanding of the interrelationships between environmental, social, and economic systems. Important areas include how to reduce waste, conserve resources, and minimize environmental degradation, as well as how to promote clean energy and reduce dependence on non-renewable resources to help individuals make responsible and sustainable choices in the use and design of technologies. However, for sustainable development to be adopted, it must be relevant to individuals or communities, include practical solutions, and involve value-based social science decision-making (Holbrook, 2009; Pavlova, 2013). Furthermore, Pavlova (2013) states that there is a lack of research in technology education that addresses transformative teaching and learning.

Critical Thinking Competency in Technology Teacher Education and ESD

Achieving significant progress in sustainable development demands a deliberate shift in our mindset and behaviour. To tackle sustainability challenges effectively, individuals must evolve into agents of change for sustainability (Leicht et al., 2018). This transformation necessitates equipping them with the requisite knowledge, skills, values, and attitudes to actively advance sustainable development. Axell (2019) suggests that today's learners need to develop critical thinking competency to be able to make informed decisions about issues related to technology and its impact on people, society and the environment, and therefore need to be emphasised in technology education.

The SDGs serve as a framework for integrating ESD, with critical thinking recognised as a fundamental competency within this educational approach (UNESCO, 2017). Critical thinking entails an individual's ability to engage in higher-order cognitive processes that encompass analysis, synthesis, problem recognition, problem-solving, reasoning and evaluation (Taimur & Sattar, 2019). This means that to foster critical thinking, education must cultivate learners' ability to analyse, synthesise and evaluate information, and to use these cognitive skills to make informed judgements. Critical thinking also involves the ability to reflect on one's values, perspectives, and behaviours. Nonetheless, as noted by Taimur and Sattar, engaging in critical thinking during problem-solving isn't an innate skill. Developing critical thinking requires self-awareness and other necessary traits that enable individuals to articulate their analyses, interpretations, and evaluations of judgments made. In addition, Facione et al. (1995) suggested that individuals who lack openness may have difficulty accepting perspectives that differ from their own, thus hindering their ability to explore different viewpoints before reaching conclusions.

Since individual agency is crucial for sustainable development, both from a learner and a teacher perspective, inner qualities and capacities for transformation have gained attention (Ivanova & Rimanoczy, 2021; O'Brien et al., 2013; O'Brien & Sygna, 2013; Wamsler, 2020; Wamsler et al., 2021; Wamsler, et al., 2022). Inner qualities relate to the "why" in ESD and the transformation of personal beliefs, values and worldviews is considered the most powerful source to transform actual outcomes in practice (O'Brien & Sygna, 2013; Wamsler et al., 2021). Consequently, sustainability education requires more than "business as usual" to promote changes. In a review by Wamsler et al. (2021) it is put forward that the lack of individual agency is consistent, mainly due to structural constraints. However, a transformation of learners' mindset can be achieved in different ways, both as an end and means (e.g. Ivanova & Rimanoczy, 2021; Wamsler, 2020; Wamsler et al., 2022). In such processes, inner qualities must be addressed by giving opportunities for learners to include self-awareness, empathy, sense-making, a sense of purpose, and a sense of empowerment (Wamsler et al., 2021).

In the context of technology teacher education and ESD, transformative teaching and learning are considered essential for fostering the knowledge, skills, attitudes, and values needed to address complex sustainability challenges (Pavlova, 2013). It equips student teachers with the capacity to critically analyse environmental issues, make informed decisions, and actively participate in shaping sustainable futures. However, as highlighted by Taimur and Sattar (2019), numerous teachers have yet to receive education on ESD during their teacher training. Integrating ESD into teacher training programs is crucial, as it provides teachers with the opportunity to acquire the essential knowledge and skills needed to actively engage in sustainable development initiatives.

Method

This study is part of a larger project including researchers and teacher educators at a university in Sweden, and teachers at a MTRF, where a new teaching module in technology was developed. This paper presents the first iteration of a Design-Based Implementation Research (DBIR) on the teaching module. In the module, activities and assignments were oriented towards technology teaching with pedagogical considerations about sustainable development (SD), the development of professional knowledge and the integration of both conceptual and practical aspects of technology teaching.

The DBIR Approach

DBIR involves multiple stakeholders in the research design, merging design-based research (DBR) focused on classroom contexts with implementation research (IR) centred on organisational settings (Fishman & Penuel, 2018; Fishman et al. 2013). DBR, or educational design research (EDR) (McKenney & Reeves, 2018), explores new educational concepts in their intended settings, while IR examines the rollout of programs or policies (Century & Cassata, 2016). DBIR aims to study stakeholder interactions during implementation to improve both design and implementation processes.

Our project incorporates several design principles from technology and sustainable development education literature to identify study outcomes. A critical principle is using DBIR as a methodology to bridge the gap between innovative educational practices and sustained change in classrooms. This requires iterative and collaborative design efforts among stakeholders. Another principle emphasises cooperation to foster integration across different educational layers. Policy documents and curricula often mandate SD in education, a challenging goal for teachers. Our approach includes practical and value-based considerations of SD, urging the integration of personal values into pedagogical strategies. Lastly, in technology education, there is a need to balance practical benefits with conceptual understanding. Our project seeks to enrich pupils' comprehension of technology, integrating both theoretical and practical knowledge to better meet societal demands.

In summary, our design principles are shaped by the need for collaborative and iterative methodologies, integration of stakeholder cooperation, alignment with sustainable development values, enhancement of teacher professional development, and a balanced educational approach in technology education. These principles guide our DBIR approach to create meaningful and sustainable educational changes.

The Educational Context of the Study

The educational context of this study was based on a course module within a Science and Technology course of 30 credits, which includes the subjects chemistry, physics, technology, and biology. The student teachers enrolled in the course were preparing to become teachers in primary school, grades 4–6. The student teachers took the course during their sixth semester of eight in total.

In this study, our aim is to explore what aspects student teachers experience as crucial to being able to teach technology with a sustainability edge. Focusing on this single group of student teachers, this study can be considered as a DBIR case study which delves into the student teachers' experiences from taking part in the teaching module in technology. Typically, the research design in a case study involves qualitative methods such as semi-structured interviews or observations, enabling a detailed examination of the case (Bryman, 2016; Flyvbjerg, 2006). The case aligns with the research question and is anticipated to yield profound insights into the pedagogical implications of designing and integrating technology and sustainable development in the teaching module, and what aspects become necessary to bring forward in developing student teachers' pedagogical competence.

Description of the Technology Course Module Design

The content of the technology course module focuses on teaching and learning about conceptual and procedural technological knowledge. Hence, it includes learning to work with technology pedagogically, in practical activities in combination with theoretical knowledge. In the course module, it is emphasised that to be able to teach technology, teachers need both content knowledge and pedagogical knowledge. The module was set up through collaborative planning by the involved teacher educators and researchers, and teachers at the MTRF. The module includes lectures, seminars, and workshops, both at the University campus and at the MTRF. In total, the course module includes 12 sessions which were divided into two theoretical blocks, one practical block, and one synthesising block (see Table 1). In the synthesising block, the student teachers were planning and enacting technology teaching using knowledge captured from the previous blocks.

Table 1. The technology course module

Block	Content	Activities	Organisation
Block 1 Theoretical Session 1–4	The epistemology of technology History of technology Design and technological documentation. Construction techniques, strength theory and materials.	Literature seminars with discussions Group works on lesson plans. Workshops on technological development work, technological documentation, construction techniques, strength theory and construction materials.	Four seminars, 180 min each
Block 2 Practical Session 5–8	MTRF: Work practically with technology - Mechanics and Digital Models w. TinkerCad, everyday mechanics and programming w. micro:bit.	Introduction to the MTRF. Practical technology sessions – workshops.	Four workshops, 180 minutes each
Block 3 Theoretical Session 9	Technology, human, society and technological systems.	Seminar on technological systems, sustainability, safety, ethical considerations, Life cycle analysis. Workshop with a debate on sustainable issues/technology, and discussions on ethical dilemmas.	Workshop 180 min
Block 4 Synthesizing Session 10–12	The planning and teaching of technology at the MTRF with pupils.	Student teachers plan a lesson based on one of the themes from the MTRF, i.e. mechanics, TinkerCad, programming, electronics, which they present and get feedback from other student teachers and teachers on their lesson plan. They revise and conduct the lesson at the MTRF with pupils.	Two Workshops, 180 min each + 240 min incl. 90 min lesson with pupils/group

Participants

The study includes a cohort of primary school student teachers. In relation to the introduction of the technology course module, we informed the student teachers about our study and asked whether some of them might consider participating. In total 12 student teachers gave their consent. In addition, eight municipal school teachers, 42 4th-grade pupils and 38 5th-grade pupils provided authenticity in the student teachers’ (training) performances at the MTRF (see Table 1, Block 4).

Data Collection

Multiple data sources were collected in several phases of the module to develop a rich and detailed picture. Initially, student teachers’ individual written reflections on technology education and sustainable development were captured. After the student teachers performed lessons at the MTRF, semi-structured group interviews were conducted using an interview guide. This included questions such as: What do you think are important aspects of successful technology education? What knowledge does a teacher need? What is your perspective on the integration of sustainability issues in relation to technological knowledge? What impact can it have on pupils' learning? What is required of you as a teacher? Each interview lasted about 45 minutes. After the module was ended, student teachers' individual written reflections on technology education and sustainable development were captured a second time.

Thematic Analysis

In this study, the analysis involved a thorough comparison of information derived from both semi-structured group interviews and student teachers' individual reflections to uncover prevalent patterns and common themes. Employing a thematic analysis with an inductive approach as outlined by Braun and Clarke (2006), the analytical process focused on describing and carefully organising the data.

The initial step aimed at familiarising ourselves with the extensive body of data. This included transcribing the semi-structured group interviews and engaging in repeated readings of the transcripts and the individual reflections for comprehensive understanding. Subsequently, transcripts and individual reflections were systematically coded and segmented into units, with the beginning and end of each unit determined by the content emphasised by the student teachers. Coding was complemented by identifying patterns in what aspects student teachers experience as crucial to being able to teach technology with a sustainability edge. The subsequent step involved a comparative examination of similarities and differences among coded units, leading to the tentative organisation of these units into themes. This process also entailed the compilation of relevant excerpts associated with each identified theme. Following this, a review of the themes concerning the collected excerpts took place to ensure that the themes accurately reflected the entire dataset. In the next last step, the characteristics of each theme were defined, and a logical naming and organisation of the themes were established. Finally, in the last step, excerpts were carefully selected to represent the identified themes, forming the basis of the analysis that addresses the research question posed in this study.

Results

In this section, we present the results in terms of what aspects of the student teachers' experiences were seen as crucial to their ability to teach technology with a sustainability edge. The findings are presented as themes, including excerpts, based on the analysis of the individual written reflections (R) and the semi-structured group interviews (G). The themes are:

- Knowledge in technology and its relationship to SD.
- Critical thinking competency.
- Inner qualities.
- Pedagogical knowledge of how to teach technology with an SD edge.

Knowledge in Technology and its Relationship to SD

All student teachers expressed that it is crucial to have deep technological knowledge as well as to be able to see the relationship between technology and sustainable development. For example, Kim suggests in the written reflection that knowledge in both areas is necessary to be able to teach pupils technology with sustainable development.

Good knowledge of technology and sustainable development...you need a solid knowledge base in the whole area to be able to communicate this effectively and appropriately to your pupils. (Kim, R)

In the group interviews too, the student teachers could describe how important it is to have specific content knowledge about technology as it relates to sustainability, and how a lack of this can lead teachers to avoid important content in the classroom because they are unsure of what it is and how to include it.

[...] we organise the structure of the lesson based on the knowledge we have. We might not have chosen to talk about the recycling ladder [Lansink's ladder] if we didn't know anything about it. So, you kind of actively choose what to focus on based on your prior knowledge [...]. (Kris, G)

Most student teachers emphasise the importance of understanding the relationship between technology and sustainable development in order to plan lessons that promote pupils' understanding of this relationship. Several of the student teachers described how they had never been taught about technology related to sustainable development. In the group interviews, the student teachers describe the transformation they have undergone during the course and how it has affected their way of thinking about the relationship between technology and sustainable development. For example:

I wasn't taught how to think about sustainability in technology before [...]. So, it has become sort of a bigger part of how to think about it. It's usually okay, we should include sustainable development, but how do I include it? So, I gained more insight into how to integrate it into my teaching. (Rene, G)

Many of the student teachers emphasise that both knowledge of technology and knowledge of sustainable development are necessary to make informed decisions and take positions on technology in different situations. Content knowledge of technology facilitates taking a stand on issues of sustainable development and what the consequences might be. This needs to be considered not only in a local context but also in a global context. For some student teachers, integrating sustainability and technology was a new way of thinking and now it seems obvious that teaching technology should always be linked to sustainability. In her written reflection, Jackie suggests that to understand the impact of technology on society, the environment, and people, one needs to know about the technology itself, and in Jackie's own words:

This will reduce the risk of making uninformed and irresponsible choices that may seem exciting and revolutionary at first but turn out to have devastating consequences and hinder sustainable development. (Jackie, R).

Additionally, for some student teachers, it is important to see the impact of technology from different perspectives, supported by knowledge of the technology itself. That is, you need some basic knowledge to be able to critically analyse technology, share experiences, and discuss technology with others.

Critical Thinking Competency

The student teachers describe critical thinking as an important competency for understanding and teaching technology in the context of sustainability. Critical thinking is described as being underpinned by both technological knowledge and knowledge of sustainable development, as well as the ability to see the relationship between technology and sustainable development. Concerning critical competency, student teachers mention necessary skills such as problem identification and problem-solving, as well as the ability to observe, analyse, evaluate, take different perspectives, draw conclusions, and collaborate. First, as Kit puts it, one has to have the facts and information, i.e., knowledge of technology as well as an understanding of sustainable development:

> *Once the information and facts have been gathered, they need to be organised, and this is where both evaluation and analysis skills are important. (Kit, R)*

Second, skills such as observation and analysis of what you see are necessary to be able to make decisions. This includes having analytical skills that help the teacher to take the subject knowledge to a higher level, which also promotes reflection, widens perspectives, and encourages decision-making on issues of technology in relation to sustainable development. All in all, this serves critical thinking skills. But being able to analyse, pose questions, and make decisions is not enough. As Charlie suggests, you also need to be able to identify problems and find and present sustainable solutions related to technology.

> *[...] As a teacher, developing the ability to analyse information and evaluate different perspectives is crucial. The ability to question claims and draw conclusions. Another good quality is the ability to solve problems. The ability to identify and solve problems is an important aspect of technology and sustainable development. This means finding sustainable solutions to challenges such as environmental impact and social aspects. (Charlie, R)*

Third, critical thinking skills include both the ability to think individually and to collaborate with others. That is, student teachers need to be able to understand other people's perspectives and ways of thinking to develop new ideas and solutions.

Inner Qualities

Many of the student teachers expressed inner qualities such as a sense of self-esteem, confidence, courage, creativity, empathy, and a sense of empowerment. All of these are put forward by the student teachers as important aspects of the role of a teacher. These kinds of inner qualities fuel the student teachers' engagement and interest in teaching technology and help them deliver lessons that, in turn, can lead their pupils to learn about and evaluate sustainability issues related to technology. The inner qualities can be rooted in both deep content knowledge and an established critical thinking competency that make student teachers confident in their role as teachers. As Robin expresses it, deep content knowledge fosters confidence in teaching technology. It keeps a teacher engaged and motivated, which translates to her pupils:

> *Having a deep knowledge of the subject increases my confidence as a teacher and I am not afraid to face questions from pupils because I feel confident in the subject. (Robin, R)*

The student teachers also describe that knowledge of the subject promotes a sense of confidence in understanding what sustainability is in relation to technology, and this confidence helps when it comes to analysing and making decisions on sustainability issues. Alva adds that the most important aspect for a teacher is to have the courage to implement technology lessons integrated with sustainability. If the teacher lacks this, it will affect the learning:

> *[...] The most important component in my opinion is that you as a teacher have the courage and the knowledge to actually implement these things. [...] If the teacher lacks this, the pupils will lack this knowledge and it will be a negative cycle. (Alva, G)*

Kit mentions that empathy, along with curiosity, are important aspects. She suggests that curiosity is important to learn more about issues related to sustainability and technology. Empathy is necessary to understand how technology affects others besides oneself. The lack of these qualities makes it difficult to understand the relationship between technology and sustainable development.

> *If you can't empathise and understand how your actions affect other people's lives and quality of life, it can be difficult to understand the connections that are necessary for sustainable development. [...] (Kit, R)*

Among the student teachers, there are accounts for the necessity to think outside the box and to find new approaches, especially in the classroom. Several of the student teachers also mention motivation and engagement as important, as well as the desire to influence the evolution of our world toward sustainable development. They feel empowered when they have enough content knowledge about technology and sustainable development, and this makes them more engaged and motivated to teach pupils in this area.

> *If I, as a teacher, have good knowledge, it is also easier to be committed and motivated, which in turn leads to more successful teaching and can also increase the motivation of the pupils when they see that their teacher is committed. (Robin, R)*

Some students suggest that it is important to create a learning environment in which pupils can engage with and become involved in issues related to technology and sustainable development. This is linked to the student teachers' aptitude and empowerment is present in their descriptions. If they are empowered to teach from a sustainability perspective, not only in technology but also in other subjects, this will show a real commitment to the pupils. They, in turn, will experience that it is important to learn, and they are likely to become more interested.

Pedagogical Knowledge of How to Teach Technology with an SD Edge

Several of the student teachers expressed that it is not enough to have content knowledge about technology and to understand how it relates to sustainability. They need to have pedagogical knowledge of how pupils understand the content and how to translate that knowledge into something their pupils can understand. This includes knowledge of what content needs to be addressed and knowledge of what classroom activities might be appropriate to make the content understandable. One example is as follows:

[...] You should also take into account the group of pupils you are dealing with by observing their interests and prior knowledge in the field to select the knowledge that the pupils need to develop and work on based on the social, economic and environmental aspects of sustainable development. (Jackie, R)

The importance of both being confident in the subject and being able to find the right level for pupils, both in terms of teaching activities and what they need to learn, is also suggested by student teachers. Sometimes this is emphasised as the need to be able to handle situations that may be difficult for pupils, such as how to interpret a particular sustainability issue. In addition, a teacher needs to be able to transform his or her knowledge of technology and SD and know how to address it in terms of both conceptual and procedural knowledge related to sustainability issues. Teachers also need to be able to plan and implement classroom activities that develop critical thinking skills, such as the ability to analyse and reflect:

[…] For teaching to be successful, it is important to work on the skills that develop pupils' analytical abilities, so you need to plan your teaching to develop these skills. (Alva, R)

This includes implementing activities that make pupils aware of the relationship between technology and sustainable development. In such situations, content related to technology and sustainable development can be complex to understand, which requires specific teaching methods to engage pupils' interest and develop their critical thinking skills.

It's not just about transferring knowledge, it's about teaching pupils to think and act as problem solvers. You should also encourage them to question and develop their critical thinking skills. (Kim, R)

Summary of the Results

The four themes identified indicate interwoven aspects that are necessary for student teachers to develop in order to be able to teach technology integrated with sustainability. Technological knowledge and knowledge of SD, as well as understanding the relationship between them, are necessary to develop and enable critical thinking competency. This competency includes skills such as problem identification and problem-solving, as well as the ability to observe, analyse, evaluate, take multiple perspectives, and draw conclusions. By having these skills and abilities, student teachers become more knowledgeable and can take positions on technology in relation to sustainability. In addition, technological knowledge, SD knowledge, and critical thinking competency promote student teachers' inner qualities such as a sense of self-esteem, confidence, courage, creativity, empathy, and a sense of empowerment. These are important aspects of the role of a teacher. Inner qualities drive the student teachers' engagement and interest in teaching technology. It adds to the planning and implementation of lessons that can guide their pupils to learn about and take positions on different issues where SD and technology are related. However, student teachers also need pedagogical knowledge about how to teach technology integrated with SD. They need to have knowledge of pupils' conceptions and misconceptions of the content and be able to use this knowledge when planning lessons to make the content understandable to their pupils. This includes knowledge of what content is appropriate for the age group and knowledge of instructions and activities that can be used to teach technology with a sustainability edge.

Discussion

The results of this study show that preparing student teachers to incorporate technology with a sustainability edge requires a multifaceted approach that encompasses both personal and pedagogical dimensions. The evolving landscape of technology education necessitates that student teachers possess up-to-date skills, a global perspective, and an understanding of ethical implications, including environmental sustainability. Teacher educators must equip student teachers not only with technological knowledge and skills but also with the ability to adapt to a rapidly changing technological environment and contribute meaningfully to sustainable development. This underscores the importance of integrating sustainability principles into technology education to prepare students for the challenges of the future. Taimur and Sattar (2019) have previously suggested that numerous teachers have yet to receive education on ESD during their teacher training. In our study, the results also reveal a gap in student teachers' preparedness to teach about sustainability when entering the course. Similar findings were presented by Pegalajar-Palomino et al. (2021) which underscores the gap in preparedness to teach about sustainability, indicating a lack of necessary professional competencies. However, the student teachers involved in the study describe the transformation they have undergone during the course and how it has affected their way of thinking about the relationship between technology and sustainable development. They now realise that both technological knowledge and an understanding of sustainable development are crucial to making informed decisions and taking a stand on sustainable development issues and understanding what the consequences might be. Thus, the content and activities covered in the limited time available during the course seem to bridge this gap to some extent. However, the results indicate that there is more to be done. According to the results, this implies developing student teachers' knowledge of the relationship between technology and sustainable development. This knowledge enables critical thinking competency, which promotes inner qualities like engagement and interest. This necessitates a holistic approach (Bencze et al., 2020) focusing on various technological content and skills including the ethical and pedagogical dimensions of sustainable development.

Fostering Student Teachers Critical Thinking competency

Critical thinking is identified as a fundamental competency within the framework of ESD (UNESCO, 2017). This involves engaging in higher-order cognitive processes such as analysis, synthesis, problem-solving, reasoning, and evaluation. Moreover, critical thinking entails self-reflection on one's values, perspectives, and behaviours. The results show that the student teachers emphasise critical thinking as crucial for grasping and teaching technology in relation to sustainability. They highlight its reliance on both technological and sustainable development knowledge, along with the capacity to discern the connection between technology and sustainability. Key skills mentioned by the student teachers include problem identification, problem-solving, observation, analysis, evaluation, perspective-taking, and drawing conclusions. This is similar to what previously has been suggested by Taimur and Sattar (2019) concerning critical thinking and an individual's ability to engage in higher-order cognitive processes that encompass analysis, synthesis, problem recognition, problem-solving, reasoning and evaluation. The results indicate that critical thinking also involves the ability to reflect on one's values, perspectives, and behaviours which is important for value-based social science decision-making (Holbrook, 2009; Pavlova, 2013). Nonetheless, as noted by Taimur and Sattar (2019), engaging in critical thinking during problem-solving isn't an innate skill. Developing critical thinking skills requires self-awareness and other traits that enable student teachers to articulate analyses, interpretations, and evaluations, particularly in problem-solving contexts.

Thus, nurturing critical thinking competency in relation to teaching technology and sustainable development requires a deep understanding of both these areas and pedagogical strategies that promote critical thinking. That is to integrate sustainable development principles into teaching, considering ethical implications and fostering interdisciplinary connections, as well as to integrate personal values.

Integration of Personal Values into Pedagogy

Inner qualities and capacities for transformation have previously gained attention in relation to individual agency and sustainable development (see Ivanova & Rimanoczy, 2021; O'Brien et al., 2013; O'Brien & Sygna, 2013; Wamsler, 2020; Wamsler et al., 2021; Wamsler et al., 2022). The results of this study show that several of the student teachers voiced the possession of inner qualities such as self-esteem, confidence, courage, creativity, empathy, and a sense of empowerment, all of which constitute crucial aspects of the teacher's role. These intrinsic qualities propel their involvement and enthusiasm in teaching technology and aid in the delivery of lessons that, consequently, can prompt their pupils to engage with and formulate positions on sustainability issues related to technology. Rooted in both substantial content knowledge and cultivated critical thinking competency, these inner qualities instil confidence in student teachers regarding their role as teachers. Accordingly, the results indicate the importance of incorporating personal values related to SD into pedagogical considerations. This integration serves as a guide for student teachers to understand sustainability themselves and effectively promote pupils' interest and understanding. This has previously been suggested as the "why" in ESD and the transformation of personal beliefs, values and worldviews which is considered the most powerful source to transform actual outcomes in practice (O'Brien & Sygna, 2013; Wamsler et al., 2021). However, challenges persist in fully integrating these values into pedagogy, indicating a need for further attention to inner qualities and capacities to facilitate the development of individual agency. In essence, student teachers must not only grasp technology and sustainability concepts but also internalise them deeply to effectively impart them to their pupils.

Embracing Transformative Teaching and Learning

In the context of technology teacher education and ESD, Pavlova (2013) has previously suggested that transformative teaching and learning can be considered essential for fostering the knowledge, skills, attitudes, and values needed to address complex sustainability challenges. This approach emphasises the importance of creating learning environments that encourage critical reflection, active engagement, and the application of knowledge to real-world sustainability issues. By embracing transformative teaching practices, student teachers can empower their pupils to become agents of change in building a more sustainable future.

In the initial iteration of the designed course module, provisions were made for student teachers to contemplate their beliefs, values, and worldviews, aligning with the perspectives of O'Brien and Sygna (2013) and Wamsler et al. (2021). Our data reveal numerous instances supporting the transformation of student teachers' mindsets, such as an increase in expressions demonstrating empathy towards both people and nature. However, there remains a need for further emphasis on inner qualities and capabilities to assist student teachers in addressing internal dimensions crucial for nurturing individual agency (Wamsler, 2020).

The results highlight design principles within the initial iteration of the teaching module that warrant further scrutiny. That is to advocate for developing student teachers' critical thinking competency and the integration of personal values of SD as a framework for pedagogical deliberations concerning sustainable development. While student teachers have undergone personal transformations in their perspectives on sustainability in relation to technology, challenges persist in effectively integrating activities aimed at fostering pupils' comprehension. This enduring challenge has been documented in previous research (Holbrook, 2009; Pavlova, 2013; Wamsler et al., 2021), and needs to be further investigated.

In conclusion, preparing student teachers to teach technology with a sustainability edge requires a multifaceted approach that integrates knowledge of technology and sustainable development with personal values, pedagogical competence, critical thinking competency, and transformative teaching practices. Teacher educators play a pivotal role in equipping student teachers with the necessary knowledge, skills, and attitudes to effectively integrate sustainability principles into technology education and contribute to a more sustainable future.

Limitations of the Study

A common criticism of case studies is the inability to draw general conclusions from a single case (Bryman, 2016; Flyvbjerg, 2006) and thus we acknowledge that this is the first iteration of our DBIR approach as advocated by Fishman et al. (2013). However, while the sample size is limited for drawing general conclusions, the qualitative data offers richness and depth, providing a detailed insight into what student teachers experience as crucial to being able to teach technology with a sustainability edge. The study can as such serve as an exemplifying case for the group of student teachers who may participate in similar courses. Further, the findings contribute to the collective process of knowledge accumulation in the research field (Fishman et al., 2013; Flyvbjerg, 2006). This in-depth knowledge is expected to guide further investigations on SD and guide teacher educators in what to address in technology teacher education.

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29.2

Research and Design teachers', and students' frame of reference around the concept of 'model'

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Abstract
This pilot study investigates the way that young students and teachers of a Dutch Science Technology Engineering and Mathematics (STEM) secondary school subject Research and Design (R&D) reason about the concept of 'model'. The core of the Dutch Technasium secondary school course Research and Design curriculum (R&D is in Dutch called Onderzoeken en Ontwerpen O&O) is to involve students in real-life design (or research) problems with a problem owner at a company or organisation. Students explore the nature of the design problem, establish a design brief, explore possible solutions and work out one option into a design, a prototype or a product depending on the level of complexity. Students work and learn in teams coached by Technasium teachers. Some secondary school teachers are qualified to teach at Technasium if they obtain a certificate from the Technasium foundation through a number of short training courses. They are originally teachers in various subjects like mathematics, physics, physical exercise, language and so on. The other part of the teachers has a teaching degree in R&D next to a degree in engineering. Thanks to different backgrounds the teachers offer a variety of angles and know-how in different fields of expertise needed during R&D activities. Such a composition is enriching and STEM supporting at the level of knowledge transfer. It is clear that some R&D teachers have no design pre-knowledge. A pilot survey of R&D students and teachers on the concept of 'model' within design activities unexpectedly showed similar doses of confusion about the concept of 'model' among students and teachers. Therefore, when asked to teach a concept of 'model' in design related activities teachers provided a different definition of concept. Often a physically built scale 'model' or prototype is the form of 'model' they recognize in designing. The danger of such an approach is that the students obtain different, incomplete, or incorrect knowledge about the concept of 'model' in relation to design. Therefore, the set of values and norms within the group of Technasium teachers is needed, to establish a design related frame of reference.

Keywords
STEM, Stichting Technasium (ST), Research and Design (R&D), Concept, 'model', Pedagogy of Design, Project based learning, Design Based Learning (DBL).

Dutch innovative STEM project-based course
A core goal of the 'Technasium' curriculum and of the course Research and Design (R&D), which in Dutch is called O&O (Onderzoek & Ontwerpen, 2022), is to have students involved in real- life problems set by interdisciplinary companies or organisation while learning about different technical professions. This unique approach, initiated by the Dutch Ministry of Education,

Culture and Science and set up in 2004 by two inventive teachers (Schalk & Bruning, 2014), connects companies and institutions of all sizes with secondary schools and supports the learning of engineering through research and design. As a primary goal of the subject, students get acquainted with different professions and issues in engineering at an early age. This helps them to make an informed decision when choosing their future studies (Van der Veen & Blume-Bos, 2015). The final assignment, the Master's test called in Dutch 'Meesterproef' was named after a piece of work made by a craftsman with the aim of becoming a member of a guild (ANW r.d.) The Master's test also involves Polytechnic or University experts as a support during the project (Onderzoek & Ontwerpen, 2022). The professional companies that own problems are not necessarily involved in engineering but do need engineering support. The company or institution provides these tasks in consultation with a teacher through project assignment descriptions. 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.

Project assignments 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 project assignments are in lower grades written by the teacher (in consultation with the companies, assignment field experts and/or institutions) but later in their R&D career, in upper grades, the students will go out to find problem-owners themselves and write their own projects in consultation with the company or institution. The projects run for about 10 weeks in the lower grades (in grades 7–9, ages 12–15); and in the upper grades, students choose projects themselves which last for 16 or 20 weeks (in grades 10–12, ages 16–18). In upper grades R&D is an elective subject. R&D aims to integrate different disciplines from natural sciences into technological research and design projects through real life problems. Research and Development (R&D) is a subject that contributes to a more comprehensive approach, aligning with the core concept of the Science, Technology, Engineering, and Mathematics (STEM) movement. STEM education is based on the principle of interdisciplinary learning, aiming to educate students in four specific disciplines through an applied approach. STEM involves integrating disciplines into a cohesive learning based on real-world applications (Horn, 2014).

Disruptive innovation (Christensen et al., 2016) refers often to a technological development, for example, Artificial Intelligence robots, that significantly affect the way markets or industries operate. The need to equip students with the skills for 'disruptive thinking' is recognized by some governments (Innovation and Science Australia, Australian Government, 2017). Although the need for STEM education is in general recognized the implementation of STEM education is complex and challenging due to different approaches, practical, pedagogical, and didactic implementation obstacles advocating the need for productive alignment of disciplinary knowledge with interdisciplinary contexts (Lyn, 2020).

STEM R&D teachers

A significant portion of the latest and most valuable knowledge encompasses multiple subjects. Interdisciplinary STEM education has the potential to inspire students towards careers in STEM fields and could enhance their engagement and proficiency in mathematics and science. Ensuring effective STEM education is imperative for the future accomplishments of students.

Equally crucial is the preparation and support provided to teachers of integrated STEM education to realise these objectives (Rossouw et al., 2011).

But as we know the most integrated STEM teachers are originally educated to teach subjects in single disciplines. This applies to R&D teachers as well. At the moment, all secondary school teachers are qualified to teach at Technasium if they obtain a certificate from the Technasium foundation through a number of short training courses at Technasium Academie (Technasium Academie 2023). The only difference is the field of teachers' activity known as first grade (upper grade 16-18 years) or second grade (lower grade 12-15 years) of secondary teaching. This means that the R&D teaching team is usually composed of many different teachers who have competence in different subjects from physics to history to languages but also on different levels of the content. Implementing a relatively new integrated STEM subject such as R&D as part of the curriculum presents teachers who teach the subject with several challenges. They still must master the content of the new subject (Stohlmann et al., 2012). They also need to get used to project-based and student-centred teaching methods and pedagogical approaches that contain different jargon and concept descriptions (Henze et al., 2007). This makes the new integrated STEM subject R&D potentially more difficult to teach. Furthermore, they need to possess effective communication skills to establish valid contact with companies and institutions, as well as to define valid project design problems or research questions.

Importance, defining and exploring concepts

During the execution process of research or design assignment, technological education and technological literacy in general is an important aspect of the R&D subject. The outcome of a Delphi study on the set of basic concepts that are most relevant for technology education was that the following five concepts were the basic for technology education: design-as-a-verb (‘designing’), systems, modelling, resources, and values (Rossouw et al., 2011). Therefore, we can infer that the concept of modelling is particularly important to learn accurately. The meaning of technological concepts, like the concept of ‘modelling, have in students’ minds directly affected their learning in technology because these concepts form a framework from which to construct other concepts and base actions on (Jones, 1997). Ensuring that teachers share a collective understanding of key concepts is essential for delivering a consistent, effective, and high-quality education, particularly in interdisciplinary fields like R&D. It enables teachers to provide consistency in the curriculum through effective and coordinated instruction, thereby standardising the learning experience. Students benefit by receiving clear and unambiguous curriculum content and can apply learned concepts in various interdisciplinary contexts.

There are several possible approaches for learning concepts. One of them, learning by design (LBD) is a project-based approach. The way in which this approach stimulates concept learning is by learning from experience. Learning concepts through design 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 (Van Breukelen et al., 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). Kimbell et al. (1991) described this as an iterative process of imaging (inside the head) and ‘modelling (outside the head) until sufficient details are resolved for the concept to be realised physically as a working prototype.

An interesting way to learn concepts, within the framework of course R&D, is 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 than used for designing. Need to know and need to 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 (Van Breukelen, 2017).

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 (Van Breukelen et al., 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 the design process. (International Technology Education Association, 2007). It sounds simple but concepts, such as: Designing, Modelling, Design brief are complex, dependent on professional context and difficult to define.

Defining the concept of 'a 'model' within STEM subjects

Concept of a 'model' may differ between different fields such as science and technology. This is caused the term 'model' being understood in different ways. Therefore, a concept with the same name can work out differently in different domains. What students and teachers have in mind as the concept for example of an educational physical scale 'model' of an ear, is important, because it informs how teachers and students support, communicate about, and apply it in practice. When both teachers and students have a clear and shared understanding of what a concept is, it can significantly improve the effectiveness of teaching and learning. Shared language understanding of different types and functions of 'model's promotes a common language between teachers and students. This makes communication more effective because both parties use the same terminology and conceptual frameworks. This can reduce misunderstandings and allow for a smoother exchange of ideas.

The focus of research is concept of 'model' and how it is used to communicate ideas with R&D rather than the process of 'modelling' (an R&D skill). So, what do students and teachers of R&D understand by the concept of a 'model'. Will the different types of 'model's without a science or technology purpose like playmobile horse (an abstracted physical scale 'model') also be seen as a 'model' or not? In order to explore the R&D frame of reference for the concept of a 'model', the natural science, mathematics and R&D have been examined in advance for the meaning of the term 'model' and classification of types of 'model's. Natural science includes earth science, physics, chemistry, astronomy, and biology, while mathematics is considered one of the four core subjects taught in schools, alongside physics, chemistry, and biology.

In the literature, the concept of ‘model’ is defined in various ways. Lijnse (2008), Schwarz & White (2005), and Hestenes (1987) all describe a ‘model’ as a representation of reality with a goal and an alleged area of validity. They differ in their specifics, with Schwarz & White (2005) emphasizing representation rules and reasoning structures, and Hestenes (1987) focusing on observable patterns in physical phenomena. In secondary education SLO (2020), a simplified definition is often used, describing a ‘model’ as a schematic representation of reality.

Although there are various definitions of the term ‘model’, no unequivocal meaning or definition has been found within the natural sciences, mathematics, and R&D for the term ‘model’. The definition depends on the field of knowledge. A common definition is that a ‘model’ is 'always a simplification of reality'. Reality is according to Cambridge dictionary (2023) the state of things as they are, rather than as they are imagined to be. Several scientists Wegner (2017), Buede, & Miller (2016), including Lijnse (2008), argue that a ‘model’ always has a purpose. In the absence of a definition, Van Driel et al. (1997, p. 179-180) has provided a number of characteristics by which a ‘model’ can be recognized in the natural sciences such as:

- A ‘model’ is always a ‘model’ of something, namely of an object of investigation. The object of research can be a system, but also a phenomenon, a process, a 'thing', or something that does not exist (anymore) (such as a dinosaur) or whose existence is uncertain (such as a black hole).
- A ‘model’ is a tool for research into the object in question. It is used as such because the object itself is not accessible for direct examination.
- A ‘model’ shows a number of similarities with the object of research. Thus, a statement about a certain ‘model’ can be 'translated' into a hypothesis regarding that object. Assessing such a hypothesis (if possible) leads to new knowledge about the object of research.
- A ‘model’ differs from the object of research in that reductions are applied when drawing up a ‘model’ (for example, by deliberately ignoring certain aspects of the object of research in the ‘model’), by scaling or in some other way. The pursuit of simplicity plays an important role in the development of ‘model’s (Ockham's principle).
- A ‘model’ has a built-in compromise character, and the researcher has a certain freedom in choosing a ‘model’. The research question plays a role in that choice.
- A ‘model’ is not derived directly from the object of study, such as a photograph or a measurement result. It contains elements that the object of investigation does not possess. Creativity therefore plays a role in the choice of a ‘model’.
- During a study, a ‘model’ may undergo an iterative development. The object of research is always studied in more detail.

Different classifications are possible to classify ‘model’s within the natural sciences, engineering and mathematics. This classification can be made, for example, based on a level of abstraction, the purpose of a ‘model’ or type of ‘model’. By exploring the different classifications of ‘model’s, educators could help students develop a more nuanced, flexible, and practical understanding of science, engineering and mathematics. In the classroom, not all students learn the same way. Some might grasp concepts better through visual models, while others might prefer abstract, mathematical representations. By teaching about the different types of models and their classifications, educators can provide multiple pathways for students to understand the material.

Therefore following possible classification of 'model's based on their function could help R&D students to better understand their purpose and utility in various contexts, whether it is education, research, engineering, or information management. If we classify 'model's on their function we can think of didactical (to learn, practice, assess, visualise), explorative (to experiment, optimise, simulate), theoretical (to predict, focus, generalise) or informative 'model' (to inform about structure, constraints, meaning, rules).

In architecture and industrial design, 'model's are often defined and classified based on the design process (Eger et al., 2010; Knoll & Hechinger, 2007; Karssen & Otte, 2018). Different types of 'model's are used at different stages of the design process. Usually, those 'model's then go from coarse to fine with regard to simplification of reality (level of abstraction). Abstraction is the opposite of reality according to Cambridge dictionary (2023), abstraction is the situation in which the subject is very general and not based on a real situation. The word 'abstraction' comes from the Latin verb 'abstrahere' which means: to distract. It is the act of withdrawing or removing something to focus on a sort of property.

Type of 'model's could be divided into physical like a 'model' of an ear in biology or a scaled car 'model', conceptual like electrical circuit or competition organisation schemes and symbolic like a chemistry or mathematical formula.

It seems that there is no agreement on the use of the term 'model'. There is no clear and unambiguous definition and classification available. Therefore, teachers and students have different ideas about the term 'model' (Lijnse, 2008). This makes it difficult to instruct students about a 'model' within the design process.

Exploring Conceptual Understanding

The aim of the research was to investigate the conceptual understanding of the term 'model' among R&D teachers with very different subject backgrounds and R&D students. The cause for this was an informal conversation among a small number of students in their final R&D year which revealed that the students had various frames of references of the term 'model'. After informally asking subject teachers of the R&D subject what they understood by the term 'model', these teachers also did not appear to have the same frame of reference, which may have led to different ideas about what constitutes a 'model'. It appears from various conversations that there may be no agreement on how to use the term 'model' in high school R&D education. This implies that students of R&D possibly do not receive enough unambiguous information on the topic and more attention and development of effective teaching strategies for this topic in the curriculum is necessary. Because during the execution process of research or design assignment, concept learning is a very important aspect of the R&D subject. 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).

According to Findell at al. (2001):

> *Conceptual understanding within mathematics refers to an integrated and functional grasp of ideas. Students with conceptual understanding know more than isolated facts and methods. They understand why an idea is important and the kinds of contexts in which is it useful. They have organized their knowledge into a coherent whole, which enables them to learn new ideas by connecting those ideas to what they already know. Conceptual understanding also supports retention. Because facts and methods learned with understanding are connected, they are easier to remember and use, and they can be reconstructed when forgotten. (p. 118-119).*

Lijnse (2008) states that a lot of research has been done that shows that both teachers (Van Driel et al., 1997) and students (Grosslight et al., 1991; Vollebregt, 1998) have all kinds of problems with ‘model’s. He cites the statement of Schwarz & White (2005): “there is ample evidence that students may not understand the nature of ‘model’s or the process of ‘modelling even when they are engaged in creating and revising ‘model’s”. Teachers and students therefore have problems using ‘model’s. How did that happen?

The Technasium has also not provided a definition of the concept of a ‘model’ within subject R&D. In secondary education, individual subject teachers may explain the term ‘model’. However, the question is whether this also happens in interdisciplinary subjects such as R&D. As previously stated, at the moment, all secondary school teachers are qualified to teach at Technasium if they obtain a certificate from the Technasium foundation through a number of short training courses at Technasium Academie, (Technasium Academie 2023). Only difference is the field of teachers' activity known as first or second grade of secondary teaching. This means that the R&D teaching team is usually composed of many different teachers who have competence in different subjects.

Ensuring that teachers have a shared understanding of key concepts, such as the ‘model’, is crucial for delivering consistent, effective, and high-quality education, especially in interdisciplinary fields like Research and Development (R&D). This shared understanding enables teachers to align their teaching methods, ensuring a cohesive and coordinated approach to instruction. As a result, the curriculum becomes more standardised, providing students with clear and consistent learning experiences. When teachers share a common understanding of concepts like ‘model’,' they can integrate them seamlessly into their lessons, making the content more accessible and relevant to students. This consistency in instruction allows students to grasp complex ideas more effectively.

As research about conceptual understanding on the concept of ‘model’ is not new in the field of science and mathematics, but it is important to recognize that in the field of R&D pedagogy, this is one of the first pilot studies on the understanding of the concept of ‘model’ among students and teachers. A pilot survey among students and teachers was designed to explore the diversity of interpretations of the term among the students.

Research method

The first part of the research was a survey consisting of three parts. First part were open-ended questions about the different types of 'model's to assess the previous knowledge of students and teachers, as well as their understanding of the concept of a 'model'. In the second part of the survey, students were presented with pictures of various types of 'model's. This section aimed to assess the ability of both students and teachers to recognize and identify different types of 'model's. The third part of the survey consisted of a multiple-choice question. This section aimed to gauge the students' understanding of the purposes behind creating 'model's. The survey was conducted among three groups: one comprising twenty-two novice students aged 12 in the lower grade, another consisting of nine students aged 17 in the upper grade, and a third group comprising 14 R&D teachers. The second part of the research involved a small comparison of the answers provided by five R&D teachers to a multiple-choice survey based on the characteristics of a 'model' from the literature according to Van Driel et al. (1997) and Wegner (2017).

Results part one

First part of the survey were open-ended questions about the different types of 'model's to assess the previous knowledge of students and teachers, as well as their understanding of the concept of a 'model'. The first question: "What is your definition of a 'model'?" reveals an overlap in goal- and example-oriented definitions in all three groups highlighting that 'model's serve as simplified representations or descriptions of reality and can be used as examples for something. Furthermore, the definitions given were diverse.

The question of why we create 'model's uncovers different perspectives between students and teachers. While students, both in their first and last year, focus on the purpose of 'model's, such as testing or exploring and emphasize the benefits and advantages of creating them, such as providing visually appealing representations of how something looks or works, teachers, on the other hand, emphasize the clarifying, communicative, and explanatory role of 'model's, as well as the benefits of visualization that they offer. Even though a definition from literature also clearly plays a role here, namely that the 'model' always has a purpose, Wegner (2017), it emerges that description of the purpose of the 'model' changes with the role that respondent fulfils within the school. The students opt for informative or explorative functions, such as testing and presentation, while teachers choose didactic functions, like clarification and explanation.

In the second part of the survey, students were presented with pictures of various types of 'model's, see Figure 1. This section aimed to assess the ability of both students and teachers to recognize and identify different types of 'model's. From the answers, we observed that physical 'model's which are very close to reality such as scaled car 'model's, villa maquettes, cardboard Vespa were recognized as a 'model' by all groups. By lower grade 12-year-old (first year of secondary school) students' recognition of 'model's mostly remained at physical level, while in upper grade by 17-year-old (the last year of secondary school) was an increase of recognition of conceptual and symbolic type of 'model', see Table 1. The interpretations among teachers varied greatly and show in % less confidence in recognition of the 'model' than last year students.

Next to the picture of the 'model' (see Figure 1), the following statement was placed: "This is a 'model'." Do you agree, disagree, or not know?

Figure 1. Two 'model' examples: scale car (www.modelwereld.eu) and mathematical formula.

Table 1. Results overview - rough division in two-step level from remarkably close to reality to different from reality

1 = low level of abstraction, remarkably close to reality, physical

2 = high level of abstraction, a 'model' differs from reality, conceptual or symbolical

This is a 'model'. Yes, No, I don't know	Twenty-two students first class high school	Nine students last year high school 9	Fourteen teachers from one school
1 Scaled car physical	yes 73% no 27%	yes 100%	yes 93% no 7%
2 Villa maquette physical	yes 100%	yes 100%	yes 86% no 7% do not know 7%
3 Playmobil horse physical	yes 32% no 54% do not know 14%	yes 44% no 56%	yes 50% no 50%
4 TV schema conceptual	yes 50% no 45%, do not know 5%	yes 89% no 11%	yes 58% no 21% do not know 21%
5 Mathematical formulas symbolical	yes 13% no 73% do not know 13%	yes 56% no 44%	yes 14% no 72 % do not know 14%
6 Organisation schema - organogram conceptual	yes 5% no 73% do not know 22%	yes 56% no 33% do not know 11%	yes 28% no 58% do not know 14%.
7 Map of the Netherlands symbolical	yes 33% no 77%	yes 44% no 56%	yes 28% no 50% do not know 22%
8 Paper vespa physical	yes 82% no 9%, do not know 9%	yes 78% no 11%, do not know 11%	yes 64% no 22% do not know 14%
9 FM radio schema conceptual	yes 45% no 45% do not know 10%	yes 78% no 11%, do not know 11%	yes 64% no 22% do not know 14%
10 Stuffed animal toy physical	yes 18% no 73% do not know 9%	yes 22% no 78%	yes 50% no 35% do not know 15%

The third part of the questionnaire consisted of a multiple-choice question. This section aimed to gauge the students' understanding of the purposes behind creating ‘model’s. The participants from three groups could choose from; to simplify something from reality, to calculate something, to predict something, to show correlation between quantities, to highlight important components, to learn about something, to solve a problem, to understand a problem, because an experiment in reality is too expensive, a ‘model’ does not have to have a goal, and otherwise. In all three groups, the majority of respondents (70%) selected "To highlight important components" as their answer. Additionally, among the students, two other commonly chosen answers were "To simplify something from reality" and "To test prototypes." All three answers show again a physical type of ‘model’ being recognised.

Results part two

The second part of the research involved a small comparison of the answers provided by five R&D teachers to a multiple-choice question based on the characteristics of a ‘model’ from the literature according to Van Driel et al. and Wegner (see Table 2) with the answers to an open-ended question: "What is a ‘model’?" First characteristic to choose was “A ‘model’ is always a ‘model’ of something, namely of an object of investigation” has been chosen unanimously. Second answer chosen by 80 % of teachers was a; “A ‘model’ is a tool for research into the object in question.” Least c The second part of the research involved a small comparison of the answers provided by five R&D teachers to a multiple-choice question based on the characteristics of a ‘model’ from the literature according to Van Driel et al. and Wegner’s chosen answer was “A ‘model’ differs from the object of research in that reductions are applied when drawing up a ‘model’ by scaling or in some other way.” This is an interesting answer because it shows clearly not understanding of changing ‘model’ level to abstraction.

Table 2. Results of a multiple-choice question

Characteristics of ‘model’ from literature according to Van Driel et al. (1997) and Wegner (2017)	Teachers answers	Teacher’s answers overlap characteristics of ‘model’ from literature
1 A ‘model’ is always a ‘model’ of something, namely an object of investigation.	5 x yes	5/5
2 A ‘model’ is a tool for research into the object in question.	4 x yes	4/5
3 A ‘model’ differs from the object of research in that reductions are applied when drawing up a ‘model’ by scaling or in some other way.	2 x yes	2/5
4 A ‘model’ shows a number of similarities with the object of research	3 x yes	3/5
5 A ‘model’ is not derived directly from the object of study, such as a photograph or a measurement result. It contains elements that the object of investigation does not possess. Creativity therefore plays a role in the choice of a ‘model’.	3 x yes	3/5
6 A ‘model’ therefore has a built-in compromise character, and the researcher has a certain freedom in choosing a ‘model’. The research question plays a role in that choice	3 x yes	3/5

7 In the course of a study, a 'model' may undergo an iterative development. The object of research is always studied in more detail.	3 x yes	3/5
8 A 'model' should always have a purpose (for R&D)	3 x yes	3/5
100% = 40 Similarity with features offered	65% = 26 Similarity with features offered	

Coding given answers on the open question "What is a 'model'" showed an understanding by 60% of respondents of a 'model' being a 'model' of something (object). Just one respondent (20%) has an overlap with literature drawn characteristics (Van Driel et al., 1997; Wegner, 2017) mentioning purpose and reality. Although the answers do not correlate to literature they correlate to each other. The word simplified was named unanimously, representation and scale by 60% of respondents, see Table 3. Respondents were all from the same school so this could show an already existing frame of reference.

Table 3 Identifying characteristics drawn from literature coding answers from respondents

Respondent	Answer to the open question "What is a 'model'?"
Teacher 1	A representation (3D or 2D) of a scaled-down object
Teacher 2	A representation of the original object to scale
Teacher 3	A simplified or scaled-down representation of a real object or concept.
Teacher 4	A simplified representation of reality, with the purpose of providing insight into certain properties (such as proportions, functioning mechanisms, etc.).
Teacher 5	A simplified representation of a complex system, where there are multiple possibilities/perspectives to depict this system

Discussion

It is clear from this pilot study that R&D teachers lack unambiguous knowledge about the concept of a 'model'. Regardless of the number of similarities in answers there are many differences in answers. Comparison between different R&D teams from different schools can provide more clarity about similarities which may be related to school. Nevertheless, focusing on high abstraction conceptual and symbolic 'model's which differ from reality could be interesting for further research and provide a frame of reference which can connect a curriculum and learning about different types of 'model's and their uses in R&D. In this pilot, the suitability of examples in uncovering underlying R&D concepts can still be improved. The pictures - example section was intended to assess the ability of both students and teachers to recognize and identify different types of 'model's with a focus on the level of abstraction. There are other characteristics that are important and that were not included in the study, for example the function, type of goal of the 'model'. This can be investigated in further studies together with other characteristics. This can be crucial for promoting conceptual understanding. Probably due to physical place of research that took place during R&D classes only one person of all researched in description of a 'model' named a 'model' as fashion icon. Continuous evaluation and refinement of these examples, based on research and feedback from students and teachers, are essential to ensure that they serve their intended purpose.
By carefully selecting and using examples, we can capture conceptual understanding. This pilot enriched us with knowledge about the narrow frame of reference within R&D teachers regarding the different 'model' characteristics and purposes. There is a need for more specific/varied language that would enable differentiation between the different forms that a

‘model’ within R&D takes. This pilot does not provide an answer why that is so and how we can solve it. It just indicates a problem which occurs in heterogeneous STEM subject communities than this specific R&D one.

Conclusion

The provided results highlight several interesting points regarding the definition and understanding of ‘model’s among students and teachers. One significant finding is the overlap in purpose and example-oriented definitions of ‘model’s, emphasising their role as simplified representations or descriptions of something, often referred to as reality. However, the recognition of different ‘model’s remained predominantly at physical type among young students, with an increase in recognition of conceptual or symbolic ‘model’s among older students.

Surprisingly, the recognition of ‘model’s among teachers showed unexpected variation, despite the anticipated increase in conceptual and symbolic type of ‘model’ recognition among older students. This suggests a potential gap in understanding and knowledge among R&D teachers regarding the recognition and abstraction levels of ‘model’s and does not explain increasing knowledge about type of ‘model’s in upper grades.

The majority of respondents, across all three groups, identified "To highlight important components" as the main reason for creating ‘model’s. Additionally, students commonly chose "To simplify reality" and "To test prototypes" as their reasons for making ‘model’s.

The second survey aimed to compare the characteristics of ‘model’s found in literature with those named by teachers. It revealed that teachers understood a ‘model’ to be a representation of something, often referred to as reality. The majority of teachers agreed with the statement that "A ‘model’ is always a ‘model’ of something, namely of an object of investigation." But at the same time, they do not recognise that the ‘model’ could be different from reality.

Although we can detect similarities between the teachers at the same school on the definition of concept of ‘model’, those similarities are a fraction of the available knowledge about the ‘model’s' goals and definitions. These findings indicate a need for broadening and deepening the set of values, norms, and knowledge among R&D teachers regarding the definition and use of ‘model’s. Providing teachers with more comprehensive knowledge about the characteristics of ‘model’s, considering the lack of unanimous choice among the provided definitions, is crucial to establish a common frame of reference and enhance their ability to teach students effectively. Furthermore, the absence of unanimous answers about what a ‘model’ is and why we make one suggests a potential need for cross-disciplinary courses for teachers in STEM subjects to foster a more cohesive understanding of the different types of ‘model’s across disciplines. The conceptual understanding of the term '‘model’' among R&D teachers with very different subject backgrounds, within this pilot, is incomplete and ambiguous.

Possible implementation

In order to improve the conceptual understanding of the term '‘model’' among R&D teachers, gained knowledge from this pilot, should support and encourage collaborative learning and sharing of experiences specifically for R&D teachers to delve into the concept of a 'model' and its significance in interdisciplinary fields. This could provide resources and materials to support ongoing learning and implementation of learning concepts in the classroom. Expanding the frame of reference beyond the concept of a 'model' could encompass other related technology concepts relevant to R&D education. Encouraging teachers to adapt and integrate the concepts into their lesson plans and classroom activities, fostering a culture of innovation and interdisciplinary learning. By implementing these strategies, R&D teachers can develop a strong frame of reference for essential technology concepts like 'model', design, system, empowering them to enhance their teaching practices and effectively prepare students for success in R&D fields. So by giving R&D teachers enough time to discuss their teaching and learning practices with each other, explore the concepts their students need to apply and support the unambiguous learning of concepts within the pedagogy of the subject. The form in which discussion time is used is up to the team of teachers to decide (workshop, discussion, lecture, game etcetera.)

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Applying a design approach to robotics in education

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Abstract

The integration of robots into classroom settings has a long-established presence in both general and vocational education. With the developments in Industry 4.0, the importance of robotics in schools has also increased, which has become clear through various funding programmes. Especially in general education, there is often a focus on utilising robots as a tool to provide learners with an interactive learning experience centred around feedback. This approach effectively connects theoretical concepts from the curriculum to practical real-world applications through the utilisation of robots. However, the emphasis often overlooks the robots themselves and their design elements. It is important to note that the possibility for learners to design robots for self-set goals is often limited by this traditional approach. This article introduces a methodological approach that promotes a design-oriented perspective within robotics in education. In addition to outlining the methodology, the article also presents initial examples on the implementation of this design-oriented approach in training future technology teachers.

Keywords

Design orientation, Technology education, Educational robotics, Design process

Introduction

Robots have long been the subject of teaching, both in general education and in vocational training. However, there are differences in the type of robots used in the educational context: in vocational education, the robots used are those that will be worked on later, mostly in industrial applications. In general education, on the other hand, robots are used that can be described as a didactic reduction of mobile robots with wheels (e.g. Lego Mindstorms) and which usually do not have tools comparable to industrial robots and therefore cannot perform any productive tasks. They are so simplified that the connection to real robots (e.g. to industrial robots) is not always obvious. Nevertheless, they fulfil an important function in the classroom and have so far been an important medium for digital education because they have made it possible to link the virtual and real worlds in the classroom. The code created by the students themselves in the virtual world controls the movement in the real world. The sensually perceptible actions of the robot constituted a form of feedback learning that has since captivated generations of students. In didactic research, the positive effects of using Mindstorms, Arduino etc. have been highlighted in many studies (a systematic review regarding the use of robots in education can be found in Darmawansah et al., 2023). However, these studies also show that robots were primarily used as a model for computer science education. Their reactions can be used to learn how to program and to experience the mistakes made in the process. The robot itself did not automatically become the subject of the lesson, as this requires a reference to real robots (Röben et al., 2023).

In this regard, the implementation of robot models that come close to real robots poses great challenges, especially in connection with decisions about what students should learn, which is particularly related to the diverse developments and applications of robots.

A previous study with teachers in the related project in which a total of 54 schools were equipped with robots has shown that even when schools are equipped with models of real robots, there are difficulties in implementation (especially in finding suitable contexts that motivate the students to engage with the robots as such) (Hamade & Landherr, 2023). In particular, the aspect of increasing demands in the creative use of robots will be addressed in this article and the question of the extent to which a design-oriented approach (Röben, 2023) to robotics can be promoted in general education will be explored. The robots used here were Dobot Magicians, which are based on real industrial robots and were purchased by the schools in the project. More information about the project realisation, the funding etc. can be found in Hamade & Landherr (2023). The approach presented here is based on the findings of this article (published in the course of the PATT40 conference) and on the project structure described there. The design approach was piloted with future secondary school technology teachers (for grade 5-10 (from age 10 to 16)).

Literature review: Design orientation and robotics

Technology and technological determinism

It is noteworthy that the design-orientated didactics of technology (Rauner et al., 1988; Schudy, 1999) has developed in confrontation with an opposite pole, technology determinism (MacKenzie & Wajcman, 1999). According to this view, developing technology is a social force to which societies must adapt and adjust. Any attentive newspaper reader will be familiar with calls such as: “Don't miss the boat on AI now!”. Technical products with AI are spreading rapidly in society; Amazon, Facebook, Apple and Google are bringing AI into every household (e.g. in the form of Siri, Alexa). From the past, many may remember the demands on schools to introduce computers into the classroom or CNC technology in the vocational sector. In country comparisons, the progress in the spread of mostly digital technologies is presented, the position of one's own nation is viewed with favour or criticism and one thing becomes clear: there is no discussion about the “whether”; the debate is ignited by the “how”. Surprisingly, one of the fathers of technological determinism, the American sociologist William Fielding Ogburn (1886 - 1959), formulated his thesis a long time ago. Influenced by Thorstein Bunde Veblen (1857-1929), he was one of the first to formulate the thesis of technological determinism.

His book “Social Change” from 1922 contains the famous thesis of cultural lag (Ogburn, 1922). Incidentally, he already stated in the introduction: “Never before in the history of mankind have so many and such frequent changes taken place” (Ogburn, 1922). Culture is understood here in a broad sense, which also includes industry and technology in the sense of material culture. Ogburn sees the changes in technology as the pressure generator that exerts pressure on other instances of society, including the education system, to adapt. These instances are determined by it. He sees the cause of the acceleration already observed in 1922 in the increase in inventions, which is based on the accumulation capacity of material culture. Ogburn presents the material culture of a society as if it were simply a given and had to be accepted like the next rain shower. He does not address the fact that it is the work of people, that decisions and interests are behind the spread and implementation of technology in society.

This acceleration of change in material culture is a relatively recent historical phenomenon - especially in the USA at the time of Ogburn. It only began with the start of the industrial revolution and continues to this day.

Remarkably, the birth of the robot takes place just one year before the publication of his book. This refers to the play Rossum's Universal Robots by Karel Čapek (1890-1938), in which the term robot was coined from the Czech roboti (for hard labour) and was adopted in many languages around the world. This play was performed around the world and 184 times in New York in 1922/23 and was widely commented on. In this play, the independent existence of technology assumed in technological determinism finds artistic expression and makes the robot known before it even exists technically (Jordan 2019).

What challenges does the education system face as a result of the ongoing technological revolution?

In summary, the following can be said about technological determinism:

Firstly, the use of technical artefacts in society has nurtured the illusion that technology has a life of its own. Dispelling this illusion is and remains a challenging educational task. Secondly, there are different ideas about the nature of this life of its own. While Ogburn assumes a given material culture to which intellectual culture must adapt, dystopian ideas were already developing in his time that ascribed hostile tendencies to technology. This is where representatives of the Frankfurt School such as Habermas meet conservative representatives such as Schelsky. Habermas, for example, reproaches Marx for what he believes he did not understand: “Marx never realised that this 'machinery' (and the entire social system in its wake), that technology itself and not just a certain economic constitution under which it operates, covers people, both workers and consumers, with ‘alienation’.” (Müller, 2018). In the scenarios so far, people have hardly featured as decision-makers and actors, but rather as sufferers and passive acceptors or drivers of technology. We must therefore turn to the social side of technology in the following.

Technology and the human being as a social being

In view of the penetration of information technology into everyday professional and private life, it is easy to fall prey to the theory of technological determinism. Dystopian visions have long dominated science fiction, and with the development of robots, which are also becoming increasingly present in everyday life, this development is receiving a new boost. Without ignoring the driving force behind this development, it must be a task of technical education to reduce this apparent superiority to what it really is: balance of power in which technology is shaped according to economic interests. But even classic technology, which plays a major role in a robot, is barely recognised.

Every car driver, every airline passenger on the way to their holiday destination uses technology and benefits from it, does not experience the consequences of technology on nature, but views it in terms of its benefits. The consequences of this use are not experienced through the use itself, but must be developed through intellectual work. Anyone who works with their students on topics such as ecological footprint, life cycle assessments and life cycle analyses knows how difficult this educational work is. It is an urgent educational task to make this apparent superiority of technology transparent. After all, appearances must not be taken for reality.

Getting to the bottom of appearances means, for example, examining the existence of a technical artefact in terms of its history, who designed it, who benefits from it, what effects its use has and what resources have to be used for it.

Design-orientated technology didactics

The concept of design therefore encompasses both past design, when it comes to illustrating how development has progressed up to the present, and the identification of alternatives: sustainable (co-)design of technology in a socially responsible manner, both in the present and towards future generations. The concept of design is thus also linked to de Haan's design competence (De Haan, 2008) but must prove itself in terms of technical and methodological competence in the field of technology. According to Rauner (2006), this development process is the confrontation between what is socially desirable and what is technically feasible (see Figure 1). What is technically possible in the mouldability of the material world, which is limited by the laws of nature but constantly expanded by science. Here, malleability refers to the mouldability of technical apparatuses and structures.

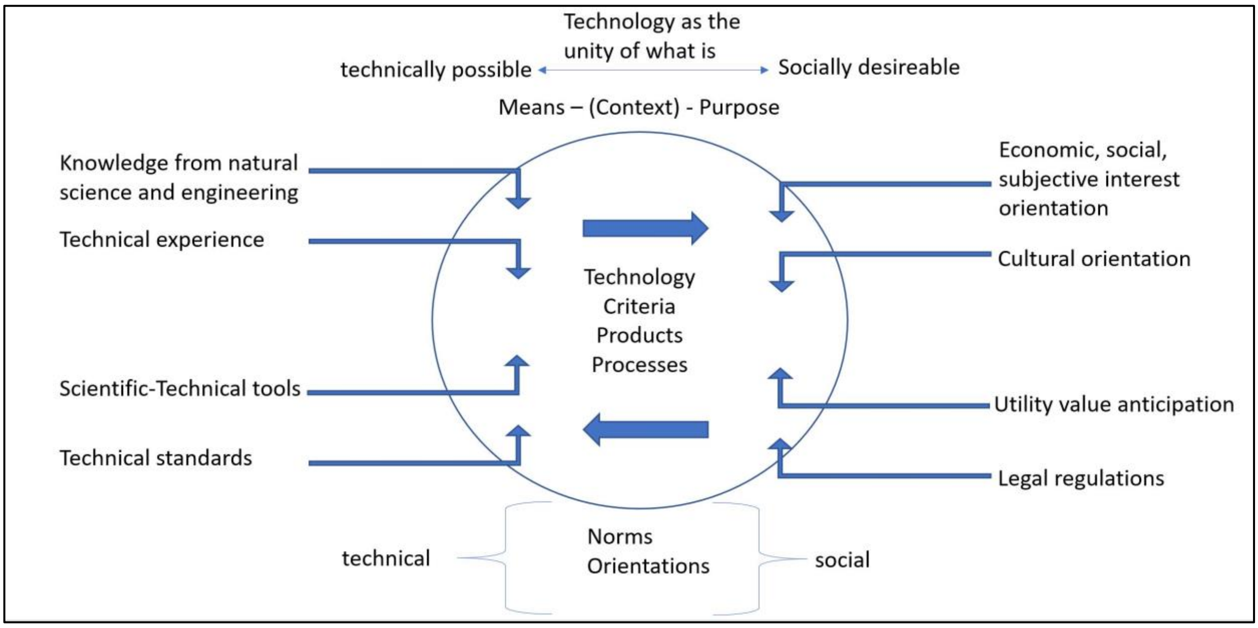

Figure 1. Technology as an end-means context according to Rauner (2006)

In the field of technology, there is a permanent, economically driven confrontation with previous limits, which is very often successfully overcome. This is because limits are not only to be found in nature, but also in the state of the natural and engineering sciences. And the experience of technical specialists in operational practice very often promotes the further development of technical systems and machines, which is why no large company refrains from awarding prizes for suggestions for improvement. However, scientific progress is at the centre of innovation research, and an entire branch of science deals with the search for applications for new findings. The social forces that characterise the process of shaping technology lie in the formulation of what is socially desirable. However, these forces are distributed very unevenly in society.

It is certainly not desirable, for example, to leave the mobility sector to the automotive industry alone. It alone is not even capable of effectively curbing fraud, as the Volkswagen emission scandal (the so-called Dieselgate, see Aichner et al. (2020)) shows, which is wrongly associated with just one company. The car industry as a whole has not stopped overproducing cars but has increased competition immeasurably. Without social control, without (co-)shaping the future of mobility, there will be no solution to this social problem.

The technical artefact as a unit of the objective, which on the one hand can be represented in scientific categories such as mass, energy and information and on the other hand has a use value that can only be grasped anthropologically with categories such as utility and satisfaction of needs, is the irreducible basic unit of technology. This is because the form and function that technical products take on in the manufacturing process cannot be traced back to science and mathematics alone. Their view of technology is truncated. The robot is a good example of a technical artefact. On the one hand, it can be analysed in the dimensions of matter, energy and information. On the other hand, it cannot be understood unless we are clear about the purpose for which it was constructed. Robots are therefore designed technology.

Understanding design as an analytical act in technology lessons

The design approach is not limited to the students' own design of technology, even if this is given great importance in this didactic approach. If you do not design the technical artefact yourself, but analyse the reasons for its design, you go back to the time of its creation. We enter the life cycle of a technical artefact and switch from the context of application to the context of production. The context of use refers to the appropriation of the technology in the professional or private sphere for the purpose of utilisation. The production context refers to the development of the technology. Both contexts allow different levels of social aggregation to be analysed. One can choose a micro level, on which the interaction of an individual with a concrete technical artefact is examined, but also a meso level, on which the interaction of social groups and institutions with technical systems is analysed. At the macro level, technological complexes that affect society as a whole, such as energy supply or transport networks, can be analysed (Häußling, 2014).

Analysing the development process of technology also makes it possible to understand how engineers work. An educational goal that has so far been little associated with technology lessons, but which is highly relevant in the upper secondary school in particular, which is fed by the resulting understanding of the development of technology as well as the need to reduce ignorance about the occupational field. A recent study summarises: “However, neither the girls nor the boys really know what is or can be hidden behind this occupational profile. [...] The engineer has nothing to do with the reality of young people.” (Cajacob & Herzig-Gainsford, 2019). However, the retrospective analysis of the design of technical products must be supplemented by a prospective assessment of future effects. Looking at the consequences of technology and empowering students to (co-)design technology is a necessity, because every technical product and artefact not only shows the intended consequences of its commissioning and use, but always also side effects, which often have unexpected consequences, especially in the case of networked technologies. The technical design task must therefore always be expanded to include a social dimension; technology must not appear as an innocent neutral in educational processes.

The creative forces at work throughout the entire life cycle must not be ignored in an enlightened technology education, nor must the social and ecological consequences of the use of technology.

Design as a generative act in technology lessons

Design appeals to special powers in people that are not awakened in purely reproductive tasks. Design intentions place demands on the technical possibilities, but these must also be realised in relation to the material and the technical possibilities.

The process of realising what was previously only imagined and the experience of this process and its result have great didactic potential both for the acquisition of technical skills and abilities and for personal development. The work processes closely associated with technology, such as inventing, designing, constructing, manufacturing, measuring, testing, repairing and recycling, also reveal insights about oneself and one's own preferences, talents and dislikes. Career guidance in technology lessons can and must build on this.

Methodology: Design process and first approach

Design process

There are already established models for the creative design process upon which the methodical sequence derived here is based. The classic model for design processes includes a divergence phase, transformation, and a convergence phase (Jones, 1970). In the divergence phase, the design space is expanded as the designer deepens their understanding of the design context, decomposes a problem, and identifies underlying issues and variables. This space is then explored through the transformation of ideas, materials, and situations in creative ways to identify new “solutions”.

Eventually, solutions converge as the designer restricts the design space by imposing constraints, removing assumptions, and realising a final design (Cameron-Jones et al., 2008). Various factors such as lateral thinking, experience, and cultural background influence the breadth of the design space. Design decisions are based on requirements and available knowledge, but often also on incomplete knowledge. The designer's experience, preferences, and willingness to take risks shape the solution space (Mader & Eggink, 2014). Building upon these models, Mader and Eggink (2014) developed a model of the design process for Creative Technology.

Their model aligns with the aforementioned aspects of design-oriented teaching but is particularly adaptable to the present basic idea from a teaching perspective due to its focus on “design beginners”, which makes it very attractive for our approach, as the students have often had no previous contact with such robots. Furthermore, the given approach fits very well, as it provides for iterative improvement loops in the design process, which is of great importance for the development of creative applications for the robots (these are particularly necessary when the first transfer of the application reaches the kinematic limits of the robot). Mader and Eggink (2014) divide the creative design process into the “ideation phase, specification phase, realisation phase, and evaluation phase.” At the outset, the design question takes the form of a product idea, a client's order, or a creative inspiration (similar to the divergence phase in the classic model described above).

The authors refer to this process as “tinkering,” aiming to identify novel applications for existing or new technologies, thereby bridging the gap between technology and user needs. As a second phase, they define the specification phase, in which prototypes are developed to explore the design space. The prototypes are evaluated within the phase, allowing for the creation or discarding of multiple prototypes. Following prototyping, the realisation of the previously developed approach ensues, which is then evaluated in the final phase. Preceding the design process in our approach is the phase of engagement with a specific technology. In the context of robotics, this phase mainly involves becoming familiar with the robots by exploring their capabilities and limitations (e.g., introduction to the technical structure and handling, peripherals, and programming of the robots).

This phase is essentially still tightly guided, as it aims to build a basic knowledge of the system, thereby enabling the design process for “design beginners” to be meaningfully initiated. Regarding the basic model of design thinking described at the outset, this upstream step is justified by the nature of the convergence phase, as design decisions must be made based on given requirements and available knowledge how it is described by Jones (1970). Ideas for designing the robot for self-set goals are gathered in the divergence phase (quantity over quality/brainstorming). In the convergence phase, the ideas for designing the robot are condensed and merged with the experiences gained in the first phase. Thus, the question of the fundamental feasibility of the ideas is pursued based on the insights gained with the robot beforehand, ultimately leading to a decision. In addition to engaging with the existing robot itself, engagement with the diversity of robots is meaningful (where are robots used, how are they categorised, what current issues exist, and what ethical debates surround robotics? What are the future predictions regarding dissemination, areas of application, etc.?). Once the basic engagement with robotics has been completed, the actual design process as described in Mader and Eggink (2014) begins. The learners have learned about a specific system and independently define a problem based on the insights gained and their individual interests (concrete examples are provided in the following section). After defining the problem, the learners (analogous to the phases after Mader and Eggink (2014)) begin to develop solution approaches (prototyping). The design space is limited here due to the robots themselves (the focus is more on designing end-effectors and the “robot-environment” to solve individual problems).

Subsequently, the prototypes are realised, and the realised solution presented and evaluated. The design process already undergoes several iterations during processes such as prototyping or realisation. It would be beneficial if there is still room for further revision after evaluation. It is plausible that an appropriate solution may not be attainable for the given problem. In such instances, it is prudent to reflect on this observation and deliberate on optimisation strategies. If the problem exceeds the capabilities of the available robot, then consideration should be given to revising or refining the problem statement, or alternatively, the development of additional prototypes may be warranted following the creation of the initial solution.

In our approach we made a course with prospective technology teachers over 14 weeks with four hours each week. The first block (two hours) of the seminar deals with the field of robotics, various types of robots and applications, which are considered from both technical and other perspectives, such as ethical perspectives. The second block (also two hours) involves practical work on the robots.

The beginning with a still very closely guided introduction to the Dobot Magicians as models (programming, networking, end effectors, sensors etc.) is followed by the actual design process in which the students realise their ideas. Examples of this can be found in the following section.

The design process itself is not a novelty in technology education, but it is intended to show the extent to which it is possible to co-design robotics on the basis of current issues, in contrast to classic approaches in robotics that focus on coding. Teachers stated that they tend to use the classic approach focussing on coding and that they lack methods to motivate pupils. The following section will illustrate this using an example.

Findings and first implementation

In order to analyse robots, we first have divided the contents regarding robotics in the seminar into the following categories (see Table 1).

Table 1. Categories of robots and robotic related content discussed in the seminar

Technical aspects	Contents
Motorisation	e.g. Electric drive, pneumatics, hydraulics
Kinematics	What movements can the robot perform with its arms, legs, wheels or wings?
Actuators	Which tools can the robot use to perform which actions?
Sensors	What signals does the robot receive from itself (e.g. torque sensor) and from its environment (e.g. LIDAR, video camera)?
Programming	What digital processing is the robot capable of (e.g. learning ability)?

Within certain limits, the students were able to choose the robots they wanted to study in more detail (see categories of robots in Table 2). Both seminars were very exciting for students, as it became clear what an important phase of robot development we are currently in. The students were given the task of searching for reliable information (for each of the technological aspects in Table 1), researching data on the above-mentioned categories, determining the development status of the robot, and finding out which company or institute developed the robot. After the research, the students had to present their results. The starting point for the practical examination of robotics within the design-oriented approach is to demonstrate possible technical solutions within the framework of a defined problem. In this initial phase, students are introduced to various programming possibilities (Teach-In & Playback, visual programming with Scratch or Blockly, textual programming in Python) and work on tasks with a defined solution path (e.g., the use of sensors, controlling conveyor belts and linear axes, sorting cubes by colour, or stacking objects with iterative increases in object height). They learn how programs are structured and which commands can trigger specific actions of the robot. This first phase serves as preparation for analysing the robot according to the design approach.

Table 2. Robot categories and examples of robots covered in the seminar

Categories of robots	Contents	Robots covered in the seminar
Industrial robots	e.g. Assembly, handling, welding	Welding robot AA IRB 7600, Daisy (recycling robot at Apple)
Cobots (collaborative robots)	Human-robot-collaboration	Kuka LBR iiwa 7 R800, Bosch Rexroth APAS assistant
Mobile robots	e.g. Bipedal robots, robots with wheels	Da Vinci, Tesla-Car
Service robots	e.g. care and nursing, communication with people (social robots), logistic robots	Atlas, Spot both Boston Dynamics, Zeno (for use with autistic children), Digit (logistics from Agility robotics), Pepper, Sophia
Research robots	Curiosity, autonomous underwater vehicles	Mars rover Curiosity, Care-O-Bot (care, Fraunhofer),

In the second phase, students make the connection between the robot they have become acquainted with in the seminar and robots from various fields of application. Examples include robotic representatives from medicine and care, industry and logistics, self-driving autonomous systems, or the military. As they further specify the exact function of the robot in the given field of application, they learn about how the robot must be constructed to fulfil its assigned task. For example, a robot designed to assist in searching for victims buried in an earthquake should be equipped with an all-terrain drive and possess a manipulator as well as sensors. An industrial robot, on the other hand, does not need to be designed to move locations itself. Instead, it requires high precision with simultaneous high payload and reach. The students approach the robots from two directions inherent to the design-oriented approach: the robot as an object that can be described in scientific categories (mass, energy, information), and the robot as a utility value, useful because it can perform a task. The students inquire about the reasons for the design: why does the technical object look this way and not differently?

In the third phase, students consider what problems could be solved using a robotic system. They find examples from everyday life or reconstruct existing robotic systems according to didactic principles (e.g., by reducing complexity) and transfer the process for solving the problem into a Nassi-Shneiderman diagram. They learn that overall problems can be broken down into technically implementable individual steps or partial problems, which can then be transferred to the robot as instructions through programming. This phase of algorithmicising prepares the generative act of realising the conceived solution: what natural laws must I consider? what technical rules and procedures must be observed?

Once the students have adequately described the problem and devised a theoretical solution, they begin building a prototype. This prototype can consist of arranging known sensors and actuators in a new configuration, resulting in a new application. Or the students use additional sensors and actuators, integrating them through the robot's interfaces, possibly with the help of additional hardware, e.g. an Arduino. During the prototyping phase, the greatest non-technical challenge for students is dealing with frustration. For example, the coordinates were not accurate enough, the sensor outputs data that is not understood, or the experimental setup exceeds the robot's working area. It is important to support students in maintaining the original problem statement, rather than changing the problem situation so that the robot can now handle it. The goal is not to design the problem but the solution path using the robot. In addition to expanding the robot with new sensors and actuators, many students also design new end effectors to give the robot new possibilities for manipulating physical objects. In this phase, students learn that the possible is not always easily achievable but that its realization must be earned with effort and patience. This process, however, also has great didactic potential, as acquiring technical skills is accompanied by personal experiences stemming from the relationship between temporary failure and eventual success.

This is a practical example of a student who considered how to use a robot to assist in surgery for a bone fracture through osteosynthesis. The student had previously delved into the history of robotics in medicine and discovered that as early as 1991, it was discussed how robots could be used to support the placement of implants. The problems of manual placement, namely inadequate precision and reproducibility, could thus be circumvented (Rall, 1991). To "generate" the problem, the student used a 3D printer to design and print two bone fragments of a humerus.

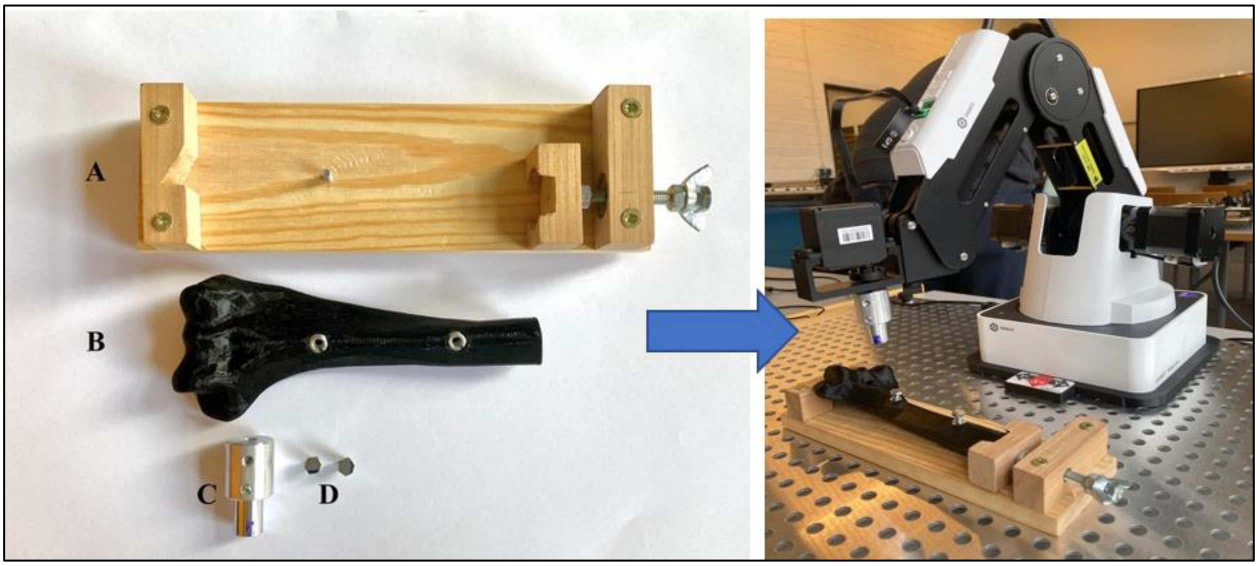

Figure 2. Left side (prototype): A: Bone mount, B: 3D-printed bone model, C: End effector, D: Screws. Right side: Testing the prototype on the robot (Mosebach, 2022).

Two internal threads were inserted to accommodate a screw, which would reassemble the broken bone using a technique known as plate osteosynthesis.

This method stabilizes the bone with a plate to increase angular stability. Additionally, she constructed a holder to securely position the object for manipulation. To enable the robot to screw into the internal thread, an appropriate end effector had to be chosen and installed. The end effector also needed an actuator to facilitate a rotating motion. Therefore, the student designed a socket attachment for a rotary servo.

Another example is illustrated in Figure 3. Here, a student addressed an issue observed in everyday university life. In the cafeteria, guests place their used knives, spoons, and forks on a tray, which is then transported to the kitchen on a conveyor belt. In the kitchen, the cutlery needs to be removed from the tray for cleaning. The student aimed to automate this process using a robot so that different types of cutlery could be sorted and cleaned separately. The student faced two challenges: Firstly, the cutlery was never positioned consistently on the tray, making it difficult for the robot to grasp using a standard end effector. Secondly, knives, forks and spoons have different shapes, requiring a solution that would allow the robot to pick them up effectively. The student solved these challenges by designing a device where the cutlery is positioned consistently for the robot to reach. Additionally, the student equipped the cutlery with points suitable for grasping using a vacuum suction cup. While the student had to adapt reality to fit the robot's capabilities to some extent, this approach represents an initial step towards designing a practical solution. By considering how the cutlery should be shaped for manipulation by a robot, the student also contemplated the reasons behind the current shapes of everyday objects.

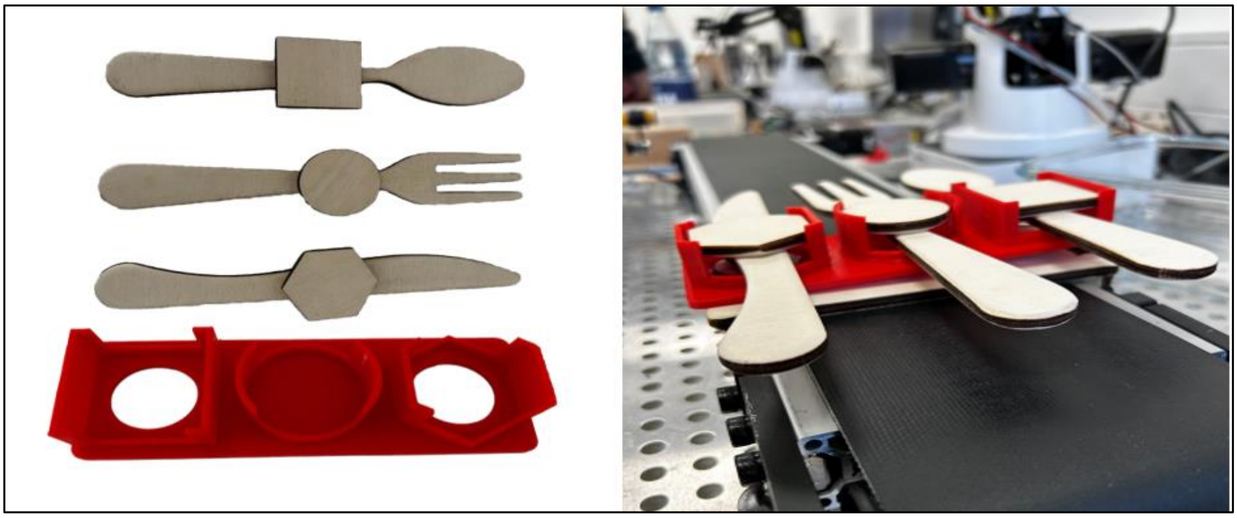

Figure 3. Left side: Designed cutlery and holder. Right side: Testing the prototype (Kleinelanghorst, 2024).

In conclusion, students thoroughly test and evaluate their prototypes by asking the following questions: Does the programming function as intended? Do the components synergize effectively to solve the problem not just adequately, but within a technically sound framework? The evaluation of prototypes goes beyond mere functionality assessments, encompassing additional criteria such as adherence to economic principles, potential social or ecological impacts, and integration of design principles.

Discussion

The design-oriented approach offers a promising avenue for creatively integrating robots into educational settings. Beyond its application in teacher training and schools, this model holds potential in engineering, product design, and science-based courses where design plays a pivotal role in learning. Departing from conventional methods, the approach places less emphasis on technical programming and more on fostering creative engagement with robotic platforms. Here, robot programming serves as a tool to realize imaginative designs. Initial implementations have demonstrated that the design-oriented approach stimulates critical inquiry and fosters innovative design practices in robotics education. Therefore, systematic investigation into observed phenomena and student feedback is essential. It is crucial to assess whether this approach effectively enhances learner motivation towards engaging with robotic technology.

Given its focus on future educators, it is imperative to extend this inquiry to broader educational contexts. Initial attempts at implementing this approach in schools highlight a trend towards openness and design orientation across different grade levels. Several critical factors merit consideration, particularly students' pre-existing mental models shaped by media portrayals lacking exposure to robotics. Tailoring the design-oriented approach to these contextual nuances requires comprehensive reconstruction of students' perceptions. This should be followed by the development and rigorous evaluation of interventions aimed at bridging the gap between existing perceptions and the transformative potential of design-oriented robotics education. Ultimately, these efforts will yield empirically grounded recommendations for effective pedagogical practices in robotics education.

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Teachers' Scaffolding Strategies in Relation to Enacted Verbal Reasoning in the Design Process

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Abstract

Learning to reason in the design process is enclosed in the process of learning to design. Hence, in this study, we explore teacher-student interactions with the aim of describing teachers' support strategies in relation to enacted reasoning in the design process in secondary school technology education in Sweden. The study deploys social cultural theory as a lens, with a focus on scaffolding means and intentions of the teacher. Relevant reasoning in the design process is theoretically framed as means-end reasoning and cause-effect reasoning. Empirical data was collected through three classroom observations with three different Swedish secondary school technology teachers, with subsequent interviews with the teachers using stimulated recall. During the observations the students were engage in different design processes. The data was analysed using thematic analysis, where themes as strategies were constructed for each reasoning type from patterns of meaning in teachers' scaffolding means and intentions. For each reasoning type, teachers employed strategies of decreasing control and increasing control. However, the enactment of these strategies differed in scaffolding intentions and means in relation to what reasoning was verbally enacted. Our findings indicate that teacher-student interactions within the design process in technology education classrooms hold significant meaning and value. This has implications for both teaching and learning in the field.

Keywords

Technology education, Design process, Scaffolding, Teacher strategies, Means-end Reasoning, Cause-effect reasoning.

Introduction

This study is an extension of a study presented at the PATT40 conference (see Hultmark, 2023), where the focus has been elaborated. The present study includes one additional observation and interviews using stimulated recall. In addition, scaffolding has been adopted as a theoretical frame.

In education, the presence of supportive teachers is paramount. Lack of support not only affects learning but also impacts students' confidence and motivation (e.g., Ludwig-Hartman & Dunlap, 2003). This also applies in technology education. The support provided by the teacher can be of different character, and ranges from for example assignments, instructions, assessment, to interactions. Experienced technology teachers emphasize that the interaction with the students is crucial and stress the importance of not leaving the students alone with their learning (Fahrman et al., 2019).

In technology education, the design process is an important content and method (Norström, 2016), which the students are supposed to develop capabilities in relation to. However, the emphasis on learning within the design process varies across curricula globally. In the Swedish context, which frames this study, learning to and about design is in focus (Skolverket, 2022). Within this process, the students must draw successive conclusions through reasoning, moving them forward in the process. Here, reasoning is defined as the process of posing premises to reach a conclusion (Walton, 1990). Therefore, learning to design entails learning to reason within the process, emphasising the significance of unpacking reasoning in understanding design practice (Cramer-Petersen et al., 2019). This emphasis on students' reasoning aligns with global curricula trends (OECD, 2023), underscoring its relevance for both teaching and learning.

However, regarding teaching, this reasoning can be transient, posing challenges for teachers in elucidating it and providing adequate support. For teachers, it becomes a multifaceted task, requiring constant adaptation to students' need and real-time situations (Seery et al., 2023; Sheoratan et al., 2024), including attending to students' emotions (Meyer and Turner, 2007; Siu and Wong, 2014). Nonetheless, there is a need for a deeper understanding of teachers' support in relation to the students' reasoning in the design process.

Background

Teachers' Support

Several theories describe how teachers' support facilitates student learning, with scaffolding being favoured through a sociocultural lens. Scaffolding, rooted in Vygotsky's (1978) Zone of Proximal Development, is described as the tailored support teachers provide for learners to progress in their process. Wood et al. (1976) describes this as the teacher "controlling" what surpasses the learner's current ability, while the learner manages what for them is possible. They further uphold that this is more effective than supporting the learner to complete tasks or leaving them to navigate processes alone. Through the teacher's scaffolding, the learner would later be able to perform the task unaided. Followingly, scaffolding contributed to learning (Stone, 1998).

Teacher support encompasses various actions, making it useful to distinguish different scaffolding. Saye and Brush (2002) distinguish hard scaffolding, which teachers plan, from soft scaffolding, situational support tailored to students' needs. Sheoratan et al. (2024) focused on soft scaffolding, exploring how three teachers scaffolded students' problem solving in design projects within chemistry education, where learning objectives related to both design and chemistry. They especially focused on scaffolding with questions and feedback, identifying that the teachers used more steering support for student actions and more exploratory support for students' thinking.

In recent years, research has been carried out investigating the technology education classroom. Esjeholm and Bungum (2013) observed teacher-student interactions in a design project focusing on technological knowledge. They identified that the teacher support was crucial for the students moving forward in the process. This support was often not in the form of instructions, but suggestions. This can be compared to Goldschmidt et al. (2014) and Kimbell and Stables (2007), who describe the teacher's role in the students' design process as of a guiding nature. Esjeholm and Bungum also identified a shift in the teacher-student interactions during the process. In the beginning phases, the teacher's support was more oriented to assisting the students towards a goal through interventions. Later in the process, the support shifted to more explorative. Svensson and Johansen (2019) also identified the nature of the teacher's support as being in the form of interventions, especially when necessary preconceptions had not been established between teacher and students. Furthermore, Lysne and Esjeholm (2021) identified that interventions and instructions was prevailing in their studied teacher-student interactions in a design project, as opposed to moderative and explorative talk.

Reasoning in the Design Process

Reasoning within the design process is elusive and can manifest in various ways. There are many who have described this reasoning, where recent focus has been on design reasoning as abductive reasoning (e.g., Dorst, 2011). However, the design process involves reaching multiple conclusions through different types of reasoning. Hence, it is deemed that a constant pendulation between different types of reasoning is crucial for process efficiency (Davis, 2011; Razzouk & Shute, 2012).

Research on reasoning in the field of design has been centred around reasoning as deduction, induction, and abduction. Cramer-Petersen et al. (2019) investigated reasoning patterns in idea generation, identifying an abduction-deduction pattern as prevalent. Similarly, deduction, induction and abduction have also been emphasised for technology education (Seery et al., 2023). However, within philosophy of technology, means-end reasoning has been highlighted as essential throughout the process (e.g., Hughes, 2009). Building on this, Hultmark et al. (2024) proposed a model for reasoning in the design process in technology education identifying two reasoning types as relevant, means-end- and cause-effect reasoning.

Furthermore, with the use of yet another theoretical frame for reasoning in the design process, Siverling et al. (2021) identified what prompted students' verbal evidence-based reasoning while working in a STEM integrated engineering design process. Using Toulmin's model (1958) to frame reasoning, they identified teachers' questions or comments containing the word "why" or encouraging evidence use prompted students' evidence-based reasoning. Nevertheless, they identified that any teacher expression sometimes served as a prompt. As can be noted, there is a lack of a common theoretical ground for reasoning in the design process. For technology education, more research is needed relating to students' reasoning in the design process, for the field to consolidate and to explore this important practice in the design process.

Aim and Research Question

The students' reasoning in the design process moves the process forward. That the students get the opportunity to explore all aspects of the reasoning in the design process is important for learning about and to design. Here, the teachers have an essential role of supporting this. However, little is known about this support. Hence, the aim of this study is to describe the support strategies used by the teacher in teacher-student interactions, based on the enacted verbal reasoning in the design process. This has been done by guidance of this research question:

What characterises technology teachers' support strategies in relation to the enacted verbal reasoning in the design process?

Theoretical Framework

We approached the research question with socio-cultural theory as a lens. With regards to the research question, both teachers' support strategies and reasoning in the design process needed to be theoretically framed. Further follows the theoretical standpoints used in this study.

Teachers' Strategies

The teacher's support strategies were framed using a model described by Van de Pol et al. (2010) based on socio-cultural theory and scaffolding. They identified teachers' support strategies as consisting of *intentions* and *means* of scaffolding. The identified three intentions, where:

- *Scaffolding of students' metacognitive activities* include scaffolding of learning of key ideas and providing support for the student to reflect and govern their own learning;
- *Scaffolding of students' cognitive activities* include to reduce the students' degrees of freedom in the task and for example simplifying the task;
- *Scaffolding of students' affect* include to have the intention of controlling students' frustration or adherence to the requirements of the task ;

These intentions were combined with six identified means for scaffolding:

- *Feeding back*: Provide information about performance;
- *Hints*: Suggestions to move forward;
- *Instructing:* Tell the student what to do;
- *Explaining*: Give more information or clarification;
- *Modelling*: Demonstration of skills or behaviour;
- *Questioning*: Ask questions that requires for the student to answer;

In this study, both the teachers' intentions and means were of interest and strategies were regarded as a combination of intentions and means. This theoretical frame governed the data collection method and were used deductively in the data analysis.

Reasoning in the Design Process

To explore the enacted verbal reasoning in the teacher-student interactions, the model for reasoning in the design process in technology education described by Hultmark et al. (2024) was chosen as theoretical framework. This is a flexible model that can be used in various parts of the design process. With philosophy of technology and technology education as a basis, Hultmark et al. describes two different reasoning types as relevant in the design process; *means-end reasoning* and *cause-effect reasoning*. Means-end reasoning is the reasoning from desired ends to means as actions, rendering in intentions to act or actions. Cause-effect reasoning on the other hand is reasoning as evaluation and prediction about causes and effects. Here, the conclusion takes the form of a belief about cause, effect, side-effect, or consequences. Hultmark et al. highlight the relationship between these two reasoning types and upholds that cause-effect reasoning takes place within means-end reasoning. A student reasoning in the design process, would constantly go back and forth between these two reasoning types (see Figure 1).

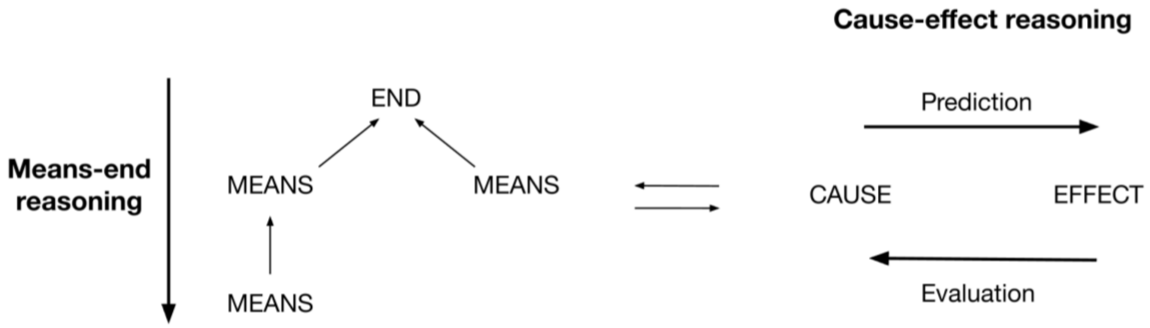

Figure 1 Schematic illustration of means-end and cause-effect reasoning as published by Hultmark et al. (2024)

Method

Data Collection

To be able to interpret and analyse scaffolding means and enacted verbal reasoning in teacher-student interactions, data was collected through observations, and video- and audio recordings in classrooms. Selection of Swedish secondary school teachers was made through a combination of snowball and subjective selection. To capture teacher intentions, the observations was followed by interviews using stimulated recall. The data collection process is presented in Figure 2.

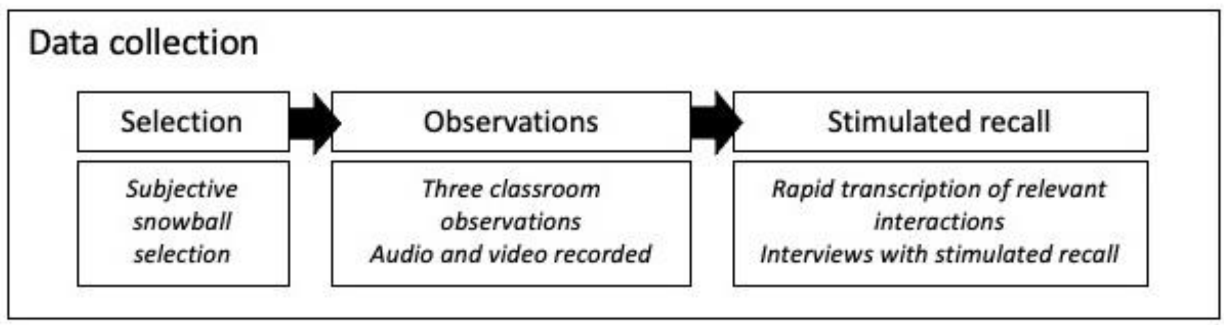

Figure 2 Illustration of the data collection process.

Selection

A combination of subjective and snowball selection (Denscombe, 2018) was used to gather in-depth data from Swedish secondary school technology teachers. Initially, technology teacher educators disseminated information about the study among their networks of teachers. From those interested, participants were selected based on inclusion criteria: secondary school technology teacher planning a design process project within the study's timeframe. Three technology teachers were selected as participants, from now on referred to as Jack, Oscar, and Harry. The teachers then proposed lessons for observation.

The teacher Jack had planned a project tasking students with designing a ventilation system, with the aim of building a model. The students were to use a small DC-motor to power a turbine controlled by a microbit. The students chose a location for which they designed their ventilation system. During the observation, the students had made drawings, and were all building models.

The teacher Oscar had planned a project where the students designed their dream house. Tasks included producing sketches, a floorplan, a three-view drawing, and a written description detailing foundation, walls, and roof decisions. During the observation, students predominantly worked on their drawings, while two were writing.

The teacher Harry had planned a project wherein students designed a small plastic car capable of forward motion using a DC-motor. Documentation was required though a logbook. During the observation, all students were building their car.

Observations

In total, one lesson per teacher was observed, each lasting close to an hour. One researcher participated during the lesson as a complete observer, refraining from interaction with the teacher or students (Baker, 2006), except to address questions related to the study. This approach aimed to minimize the researcher's influence on participants (Denscombe, 2018). However, as Baker highlights, this limited the researcher's ability to fully perceive interactions. Additionally, the multimodal nature of the lesson (e.g., Otrel-Cass et al. 2010) added complexity to the observation. Therefore, data was collected through audio recordings captured by a microphone attached to the teacher and microphones placed near each student group. Furthermore, the lesson was video recorded using two cameras to capture gestures, movements, and relevant artefacts. This approach also ensured avoiding filming none-participating students. Observations involved 17, 14, and 11 students, respectively.

Stimulated Recall

Following each observation, to capture the teacher's intentions in interactions, the teacher was interviewed. Stimulated recall was used to facilitate the teacher's recollection of interactions (Lyle, 2003), enabling them to reflect on their actions (Haglund, 2003). While video recordings are commonly used as stimuli, in this study, transcripts and still photos from videos were used to reduce reactivity. This approach aimed to enhance internal generalisation in interviews by minimising reactivity (Flick, 2018).

To prepare stimuli, audio and video recordings from the observation were manually transcribed, focusing solely on interactions relevant to the research question. The time between observation and interview was minimised to one school week to facilitate the teacher's recall of the lesson. The interviews were audio recorded.

Data Analysis

The data was analysed through thematic analysis as described by Braun and Clarke (2006), allowing for flexibility (Robson & McCartan, 2016) and the use of a combination of theoretical standpoints to identify intersecting patterns of meaning. The analysis process, outlined in phases 1-7 in Figure 3, began with syncing audio and video recordings from the observations using a computer software (DaVinci Resolve). Subsequently, 570 minutes of recordings were manually transcribed, focusing on teacher-student interactions. The audio recordings from the student groups were used when audio from the teacher's microphone was unclear. Interactions considered irrelevant to the research question were not transcribed, such as interactions unrelated to technology education. Additionally, the interviews' audio recordings, in total 147 minutes, were manually transcribed.

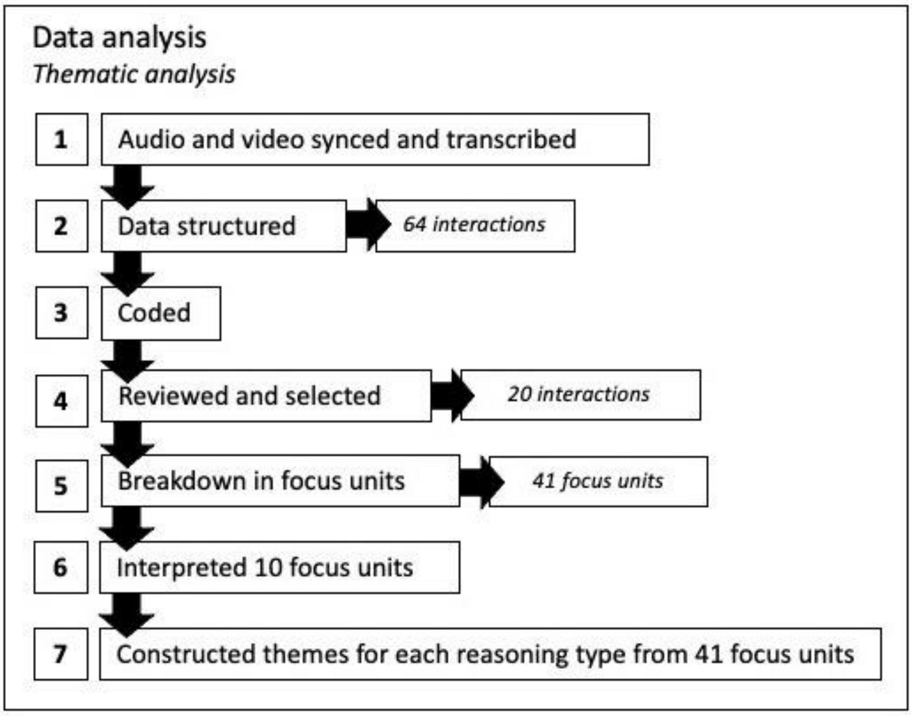

Figure 3 Illustration of data analysis process.

The data was then structured into teacher-student interactions, defined as when a conversation started between the teacher and one or more students until it ended, resulting in 64 teacher-student interactions. Each interaction contained several teacher or student speaking turns, which was deductively coded using the model for reasoning as described by Hultmark et al. (2024). Sections of teacher-student interactions were then coded based on prevailing reasoning type. Subsequently, each teacher turn was deductively coded for means of scaffolding described by Van de Pol et al. (2010), with additional contextual coding. Examples of coding are shown in Table 1. Lastly, the interview transcripts were structurally coded (Saldaña, 2017) using the scaffolding intentions described by Van de Pol et al. (2010), supplemented by inductive coding for deeper understanding and context. The deductive codes used are presented in Table 2.

Table 1 Example of coding of a teacher (T)-student (S) interaction

	Interaction	***Reasoning***	***Scaffolding means***
T	*We have a few weeks, so we actually have some time to be able to test. The tricky thing about this material. What would you say is the tricky thing about this material?*		*Repeats and clarifies that the student has time to test.* *QUESTIONING*
S	*Working with it.*	*Provides EFFECT*	
T	*Well, it's pretty hard to work with, so you get a reason why you don't want to use it. Here we have another material, so we have a few different ones to choose from.*	*Confirms EFFECT* *Suggests other MEANS*	*HINTS*

Table 2 Codes used in the analysis.

	Means-end reasoning	*Cause-effect reasoning*	*Scaffolding means*	*Scaffolding intentions*
Codes	*MEANS* *END* *MEANS-END* *CONCLUSION*	*CAUSE* *EFFECT* *CAUSE-EFFECT* *SIDE-EFFECT* *CONSEQUENCE* *CONCLUSION*	*FEEDING BACK* *HINTS* *INSTRUCTING* *EXPLAINING* *MODELLING* *QUESTIONING*	*SCAFFOLDING OF METACOGNITIVE ACTIVITIES* *SCAFFOLDING OF METACOGNITIVE ACTIVITIES* *SCAFFOLDING OF AFFECT*

Followingly, each teacher-student interaction was reviewed against the research question. Interactions where scaffolding occurred, and conclusions were drawn were selected for further analysis, resulting in a data set of 20 teacher-student interactions. These interactions were then broken down into focus units, each containing only one conclusion. Focus units containing both reasoning types (7 units) were split, resulting in 41 focus units. Of these, the teacher had reflected upon 31 in the interview, while the researchers interpreted intentions in the remaining 10 focus units based on the 31 units that the teachers had reflected upon and what student the teacher interacted with. Lastly, the focus units were sorted by reasoning type, and themes as strategies were constructed based on shared patterns of intentions and means.

Ethical Considerations

Before data collection, information about the study and data management plan was sent to the Ethical Review Authorities in Sweden for ethical review, who gave advisory opinions about the study. These were implemented in the study. Furthermore, the implementation of the study followed ethical requirements established by the Swedish Research Council (2017). This includes requirement of voluntariness and informed consent. The teacher, students and legal guardians received customised written information about the study before data collection. All participants gave written consent, except from two teachers, who gave verbal, audio recorded, consent. For students younger than 15 years, their legal guardians gave written consent as well. The students who did not participate in the study, attended the lesson in an adjacent room. All data has been stored in accordance with the Data Protection Act (GDPR).

Findings

With the aim of describing teachers' support strategies in relation to enacted reasoning in the design process, two themes for each reasoning type were constructed from analysis of 41 focus units. For both reasoning types, teachers employed strategies involving decreased or increased control. However, the specific scaffolding intentions and means differed between the strategies for each reasoning type. For instance, the primary scaffolding means for the theme of increased control differed, with suggestive Questioning predominating for cause-effect reasoning, while Instructing was more prevalent for means-end reasoning. A summary of the findings is presented in Table 3.

Table 1 For each enacted reasoning type, themes of strategies were constructed from similar intentions and means.

Reasoning type	Scaffolding intentions	Dominant scaffolding means	Constructed teacher strategy
Cause-effect reasoning	Scaffolding students' metacognitive activities	Questioning: Follow-up and counter questioning	Decreased control
	Scaffolding students' metacognitive-, cognitive activities or affect	Questioning: Suggestive questioning	Increased control
Means-end reasoning	Scaffolding students' metacognitive activities	Hints and Questioning	Decreased control
	Scaffolding of students' cognitive activities or affect	Instructing	Increased control

Cause-Effect Reasoning

When cause-effect reasoning was enacted, the teachers described their strategies in the sense of decreasing or increasing control. The teachers described that they wanted the students to think for themselves, but whether the teachers decreased or increased control were connected to certain content and teacher's preferred conclusions.

Decreased Control

When the teachers decreased control and cause-effect reasoning was enacted, the teachers had the intention to scaffold the students' metacognitive activities. Here, they manifested that they wanted the students to think for themselves, but also that they wanted the students to be able to express themselves. The teacher Oscar expresses his intention as:

> *I want to make them think for themselves. Why do they write what they write? […] They have to reflect, why do they write what they write? Is it because I have said so? Or is it because they have thought for themselves based on the questions?*

With this intention they foremost used the scaffolding means Questioning. This is also reflected in the teachers' descriptions, where they described that they use follow-up or counter-questions to let the students think, express their thinking, and reach conclusions. With this strategy the teachers pressed that they did not want to provide answers and that they refrain from directly Explaining.

How Oscar makes use of Questioning can be seen in Excerpt A, where a student asked whether it is good with many windows in a house. Oscar responds with a counter-question. The student answers the counter-question by expressing his belief of the effect of many windows. Oscar then acknowledges this through the means Explaining, but also widens the perspective by indicating other effects of windows through further Questioning.

Excerpt A

Student:	Oscar, I have a question for you. Is it really good to have many windows in a house?
Oscar:	Many windows?
Student:	Yes
Oscar:	Why would it be bad?
Student:	Doesn't it lower [intensity]? Well, you know, they take up space on the wall.
Oscar:	Well, the insulation effect is definitely worse. But what do you get with many windows? Light!
Student:	Light! And fresher air, that is, if you open them all.

Oscar describes that the intention was to not supply the student with the answer, but to make the student think for themself. Additionally, Oscar's intention was for the student to be able to express his thoughts. By the means of the counter-question, Oscar describes that:

> *I want to hear how they think. They have to be able to express their thoughts. Very important. They know why they make the decisions they make, based on whatever it is based on. Whether it's a technical task or whether it's a choice in life, for the rest of their lives. If they are not grounded in what they think and feel, then it is very difficult or those who are grounded will have a much easier time than those who are not.*

As Oscar's intention is focused on the student's verbal expression of reasoning, Oscar also makes use of the scaffolding means Explaining. Hence, when his student struggles to express the effect of windows, he confirms and through Explaining, give further support to the verbal expression of the student's reasoning by using the correct phrase "insulation effect".

Increased Control

The teachers also increased control when cause-effect reasoning was enacted. Here, the intention differed between scaffolding of metacognitive-, cognitive activities and affect. The teachers described that there are certain situations where the teachers themselves has an idea of right and wrong. In addition, they describe that drawing from experience there are certain content in the process that they do not want the students to struggle with. For example, Harry describes that the understanding of how the DC-motor works should not be an obstacle for the students. Thus, he gives the students more support in relation to such content:

> *… because some students think that if they put the motor in the wrong place, they can't change from rear-wheel drive to front-wheel drive, but it's really just a matter of changing the poles on the motor and sometimes it can be good for them to get some guidance on that. Because that should not be the hitch and it's always something they can test at the end …*

Like with decreased control, the teachers dominantly used the scaffolding means Questioning. However, there is a difference in the nature of the questions used. With this strategy, the questions they used were more of suggestive questions, guiding the students to a specific conclusion. The teachers described that they still want the students to think for themselves, hence the use of questions, but toward answers that the teachers preferred.

How the teacher Harry makes use of questions, increasing control, when cause-effect reasoning was enacted can be seen in Excerpt B. Harry askes a question for the student to reason about possible effects of the placement of the battery. The student then provides a conclusion, which was not what Harry had in mind. Thus, he follows up with suggestive questions about the weight of the battery. Followingly, the student draws the conclusion Harry is seeking.

Excerpt B

Harry:	… Why would you want to move the battery?
Student:	If it doesn't work to connect it.
Harry:	Mm, can you think of anything else? How much does that weigh?
Student:	I see, it will be too much weight on one side.

Means-End Reasoning

When means-end reasoning was enacted, the teachers also used strategies in the sense of decreased and increased control. The teachers described that they wanted the students to do themselves. Whether the teachers decreased or increased control were connected to the specific deemed need of the student.

Decreased Control

When means-end reasoning was enacted and the teachers decrease control, they had the intention of scaffolding students' metacognitive activities. Here, they described that they wanted the students to do on their own and test. Followingly, they described that they want to give the students freedom to draw their own conclusions and that this is connected to certain students that the teachers deemed could be given this freedom. The teacher Jack described this intention by pressing how he do not want to use Instructions:

> *I don't want them to follow my instructions. I want to give them some space and see how they think. I say: "You are the project manager, you decide!". I don't want to say "No, you can't do this, you can't do this. You should do this!". No, it's not good to set strict limits for students in technology education.*

With this intention, the teachers used Hints and Questioning when means-end reasoning was enacted, thus refrained from giving Instructions. In Excerpt C, the teacher Oscar makes use of Questions and means-end reasoning is enacted. The student wonders how tall the windows should be in the house he is drawing. Oscar then directs the student's attention to the windows in the classroom using a question, so that the student can relate to their size. The student can then draw the conclusion that his windows cannot be as tall as them and Oscar continues to relate to the windows in the classroom through Questioning. The student then draws the conclusion that the windows should be half the size of the ones in the classroom.

Excerpt C

Student:	So how big should it be?
Oscar:	Look. How big is a window here? [points to the windows]
Student:	I can't have windows like that.
Oscar:	No, but if you know it won't be like that, how small do you want it to be?
Student:	Half of that.

Increased Control

The teachers described that they sometimes needed to give more support to students to manage with their work in the process. Here, they increased control as a strategy when means-end reasoning was enacted. They did this with the intention to scaffold students' cognitive activities as well as affect and described that their decision to provide more support in their scaffolding was connected to the individual student's needs in the moment. In addition, they also described the importance of knowing their students and knowing what obstacles in the design project could be. With this intention they dominantly used the scaffolding means Instructing, as a strategy to increase control.

In the interaction in Excerpt D, the teacher Jack increases control and means-end reasoning was enacted. Jack has seen that a student has placed the DC-motor at a location that will prevent it from function properly. He draws the student's attention to this by the scaffolding means Questioning. When the student confirms, Jack gives a Hint about the DC-motor needing to be placed higher up from the cardboard. The student lifts the DC-motor up from the cardboard to check if that was what Jack meant. Jack then proceeds to give Instructions about means the student needs to use. He also asks a question to confirm that the student understands, and the student confirms. Jack then repeats the Instruction of means, and the student proceeds to ask what he can use to change the level of the DC-motor. Followingly, Jack gives clear Instructions of means, what the student can use, where it should be used and why.

Excerpt D

Jack	The DC motor, where is it? It's here?
Student:	Yes
Jack:	I feel that the DC motor has to be lifted up a bit. Or? Just, it's a bit close.
Student:	Like that?
Jack:	You can fix it, it's no problem. … Then, you can put something underneath from that side. For example, lolly sticks here. Otherwise, the DC motor will not work 100%. Do you understand what I mean?
Student:	Yes.
Jack:	You have to put something here on that part. So, lift it up a bit.
Student:	Okay, what can I put...?
Jack:	You can put some glue here, or cardboard. Only on this part, not on the whole. Do you understand what I mean?
Student:	Yes.
Jack:	Just here, on this part, and then glue. Because this is so small. So, lift it up in the front.
Student:	Yes.

Throughout the interaction, Jack uses Instructions with the intention to scaffold the student's cognitive activities. Hence, provides support for the parts of the task that he deems that the student is not currently capable of accomplishing independently. When Jack reflects upon this interaction, he expresses that his decision of how to scaffold is linked to the needs of the specific student:

He did not know, he has not tried yet when it connects to the microbit and works, but I know. So, I saw that, when it's supposed to spin, it will not spin, because it will get stuck in the cardboard. You see, it does not work if it is stuck like that. But [the student] has not seen it. He just puts things together. So, you have to be careful with small details with some students and give them feedback all the time.

Similarly, in Excerpt E, Oscar notices that there is a student's drawing is inaccurate. He draws the student's attention to this by Questioning. Followingly, he Hints about the means of bringing the garage down to ground level. However, the student interrupts him by expressing frustration over the change. Oscar continues to Explain to point out what is inaccurate but realises that the student is frustrated so he continues with Hinting about another means. The suggested means, a ramp, would be easier for the student to implement, as she would not have to change the current design. The student still express frustration, and followingly Oscar gives clearer Instructions of what actions the student should take. Here, means-end reasoning is enacted and Oscar scaffolds with the intention to scaffold the student's affect, trough the means Instructing.

Excerpt E

Oscar:	Is that a garage?
Student:	Mm
Oscar:	Then I would put the garage on the same level as the ground. Otherwise...
Student:	You're making it very complicated for me now.
Oscar:	If you imagine that you have a garage here, and you have 30 cm. Should you have a ramp up to the garage? You can do that.
Student:	How complicated. I don't know how I did it. Oh, I must have my [sketches].
Oscar:	Start by drawing a line at the bottom and then draw your house, the actual height of the house.

When reflecting on the interaction in Excerpt E, Oscar describes that his point of departure when interacting with students is to have high expectations, but also to change the support if needed. When the student got frustrated and did not know how to move forward in the process, Oscar changed to Instructing:

That was my starting point, talking about having high expectations based on who it is and so on. But when she didn't [understand], well, then I have to go back. So that's a typical example of when I have to go back and explain and step in.

Highlighting Differences in Strategies

For both reasoning types, the teachers used decreased or increased control as strategies. These strategies were, however, enacted in different ways depending on enacted reasoning type. When cause-effect reasoning was enacted, the teachers decreased control with the intention of letting the students think for themselves and they used Questions frequently. While, when means-end reasoning was enacted, the teachers wanted the students to do on their own, using both Hints and Questions regularly. Correspondingly, when cause-effect reasoning was enacted and teachers increased control, they often had the intention of scaffolding towards a preferred conclusion by dominantly using suggestive Questioning. In contrast to this, when means-end reasoning was enacted and the teachers increased control, they had the intention to give more support to students that needed help to manage in the process. They did this by frequently using Instructions, telling the students what to do.

Discussion

With the aim to describe teachers' support strategies in relation to enacted verbal reasoning in the design process, we constructed themes as strategies for each reasoning type with joint patterns of scaffolding intentions and means. The findings show that the teachers depending on enacted reasoning type, used different scaffolding means in connection to different intentions. This reflects previous research indicating teachers' dual roles as facilitators (Goldschmit et al., 2014; Kimbell & Stable, 2007) and instructors (cf. Lysne & Esjeholm, 2021; Svensson and Johansen, 2019) in the design process. Furthermore, the difference in the teachers' strategies of decreasing and increasing control highlight the teachers' balancing act of keeping the student motivated through moving forward in the design process, while still scaffolding for the student to be able to reach their own conclusions. Here, Instructions could be used, staying within the student's Zone of Proximal Development. For the strategies of increasing control when means-end reasoning was enacted, the knowing of students' needs was emphasized, a fundamental aspect of scaffolding (cf. Siu and Wong, 2016). Additionally, there was a notable distinction between scaffolding students' cognitive activities and affect. When scaffolding students' cognitive activities, the teacher's subject-matter didactics and experience is relevant. The teacher can decide on scaffolding based on experience. Whereas, when scaffolding student's affect, teaching and learning may need to be abandoned (Meyer and Turner, 2007). This frames the scaffolding of the teacher Oscar (Excerpt E), who in the last teacher turn adjusted his support, Instructing towards an action within the student's Zone of Proximal Development, and diverting from the cause of the student's frustration.

The prevailing means of scaffolding differing in connection to the enacted reasoning type suggests, as emphasized by Sheoratan et al. (2024, p. 163), that "teachers scaffold *doing* and *thinking* differently". However, we are cautious about implying this due to the intrinsic relationship between the two reasoning types of focus. Since cause-effect reasoning supports means-end reasoning (Hultmark et al., 2024), enactment of cause-effect reasoning may implicitly support means-end reasoning. This intrinsic relationship was evident in the data, as some interactions contained both reasoning types. This was beyond the scope of this study, but we urge for future research to explore scaffolding in connection to the relationship between the two reasoning types.

Furthermore, in the contexts of the study, learning revolves around learning to and about the design. In other contexts, such as integrated STEM projects (e.g., Sheoratan et al. (2024); Siverling et al., 2021), learning through the design process is also pertinent. At the same time, the nature of the relevant reasoning types differs for technology and science (e.g., Hultmark et al., 2024). The focus on both means-end reasoning and cause-effect reasoning, as in this study, captures and highlights aspects that are relevant to teaching and learning in technology education.

One focus within this study was the enacted reasoning between the teacher and student in the design process. Meaning that the focus was not solemnly the students' reasoning, but rather the joint reasoning among teacher and student. Other studies have focused more on the expression of the students' reasoning (e.g. Siverling et al., 2021). The focus in this study prevents us from drawing conclusions about how the teacher supported the students' reasoning. However, this study contributes to the knowledge about the relations between teacher support and reasoning in the design process. Yet, further research into the connection between teacher support and students' reasoning is needed.

In summary, we conclude that teacher-student interactions in the design process in the technology education classroom carries substantial meaning and value. This has implications for both teaching and learning in technology education. Through the interaction, the teacher can decide on scaffolding in relation to the student's learning and reasoning (cf. Fahrman et al., 2019). In this elusive process, framing the reasoning is important in shedding light on the teahers' professional knowledge.

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Design Thinking in Action: Fostering 21st Century Skills Alongside Subject Specific Knowledge at Key Stage 3 in D&T

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Abstract
This study explores the integration of Design Thinking into the Key Stage 3 Design and Technology (D&T) curriculum at a school in North-West England, focusing on fostering 21st-Century Skills alongside subject-specific knowledge. The research draws on a multiple case study approach derived from the 'Solving Genuine Problems for Authentic Users Project', which involves students aged 12-13. The paper critically examines the current educational emphasis on knowledge in England and the potential erosion of D&T's identity and scope within this framework. Through practical D&T activities rooted in Design Thinking principles, the study investigates how real-world problem-solving and innovation can be effectively embedded into early education to support students in tackling complex future challenges. The implementation of a Design Thinking Integrated Learning (DTIL) model is discussed, highlighting its capacity to engage students in empathetic, creative, and analytical processes that contrast with pervading approaches in D&T. The findings suggest that a balanced approach, integrating both knowledge and skills, is crucial for nurturing adaptable, competent learners capable of addressing the demands of the 21st-Century.

Keywords
21st-Century Skills, design thinking, constructivism, design and technology, pedagogy

The Evolution of 21st-Century Challenges
This paper extends the findings from a pilot study of the 'Solving Genuine Problems for Authentic Users Project' involving 12–13-year-old students at a school in the North-West of England (Jones, 2023). The pilot study was presented at PATT40, which prompted reflections on the study's theoretical framework, methodology and methods. This paper presents a multiple case study of four subsequent projects undertaken by students at the same school.

In the contemporary context of rapid global change, the demand for the development of 21st-Century Skills has become increasingly crucial, including in education (Koh et al., 2015).

Technology extends and enhances human capabilities, ranging from simple tools such as a hand axe to advanced instruments such as a hadron collider. All technology amplifies human potential by either simplifying and accelerating processes or providing capabilities beyond natural human limits. In recent years, technological development has increased exponentially to the extent that it has outpaced human capabilities (Liu et al., 2024), highlighting a profound evolution in the tools at our disposal. This rapid technological progress, alongside the forces of globalisation, has fundamentally reshaped the nature of the workforce (Levy, 2010; Taylor et al., 2020), requiring individuals to possess a diverse skillset that goes beyond traditional academic knowledge. 'Wicked' problems (Buchanan, 1992; Rittel & Webber, 1973) such as climate change, overpopulation, and rapid technological advancements have emerged, which are complex and ‘messy’ (Rittel & Webber, 1973), each demanding a diverse range of skills to manage successfully. Addressing the complexities of 21st-Century life and work demands that individuals are equipped with a set of specific skills, commonly known as soft or human skills. These skills are essential for successfully addressing the multifaceted challenges posed by rapid advancements in technology and societal changes (Poláková et al., 2023) that are affecting the world of work (McDiarmid & Zhao, 2023). The responsibility of ensuring individuals acquire these crucial skills falls on the education system (Koh et al., 2015; Liu et al., 2024), however it is argued that the educational models of the Industrial Age that pervade the current system are no longer adequate to equip students for such a future (MacDonald & Hursh, 2006; McDiarmid & Zhao, 2023; Petrillo et al., 2018).

While the skills that are often referred to as 21st-Century Skills are not new (Silva, 2008), they hold particular relevance today, given modern society’s complexity, particularly the increasing role of technology in outsourcing work that humans do, such as machine learning and artificial intelligence (AI). Vital capabilities such as critical thinking and problem-solving have always been important and their need in education was first recognised by classical theorists such as John Dewey (Scardamalia & Bereiter, 2014); however in contemporary times, due to the emerging demands of knowledge-based economies, those capabilities are arguably more crucial now than they were before (Bereiter & Scardamalia, 2018; Rotherham & Willingham, 2009; Silva, 2008). UNESCO has explicitly emphasised that developing these skills should not be limited to higher-level students, and instead, it is deemed crucial to support all students in cultivating meta-cognitive competencies and skills from the very beginning of formal education (Scott, 2015). While there is a broad consensus on the need for 21st-Century Skills, there is debate on what constitutes these skills and there is a lack of universal definition (Joynes et al., 2019), which is evident in the many frameworks that have emerged globally to support educators in fostering the many skills deemed imperative in the 21st-Century.

Knowledge, Skills, and the Place of D&T

The framing of 21st-Century Skills as a construct in education could be described as a “crowded space” (Foster & Piacentini, 2023, p.9), with the use of differing terminology such as 21st-Century Skills, interdisciplinary skills, and soft skills, for example, creating ambiguity (Kelley et al., 2019; Miliou et al., 2023) . The term ‘competencies’ is often used interchangeably with ‘skills’, but it is also often considered in a broader sense as a set of skills, knowledge, and attitudes that, together, meet a complex demand (Ananiadou & Claro, 2009). There is no single prescribed approach to educating young people for the 21st Century (Scott, 2015), necessitating the development of many frameworks. A meta-analysis completed by Voogt and Robin (2012) identified a range of frameworks that were developed to define and guide the integration of 21st-Century Skills within education. A number of these frameworks have undergone several revisions since the authors’ meta-analysis, and many have since ceased to develop any further. One such framework is the Assessment and Teaching of 21st-Century Skills (ATC21S), which focuses on ways to assess and teach skills such as critical thinking, problem-solving, collaboration, and digital literacy. It seeks to develop methods for educators to incorporate these skills into their teaching practices (Griffin & Care, 2015). Another framework is the OECD’s Future of Education and Skills 2030. The OECD framework focuses on student well-being and agency, incorporating a range of cognitive, social-emotional, and physical skills. It also focuses on adaptability, problem-solving, and the ability to engage with others in a globally interconnected world (OECD, 2019b). Of all the major frameworks available, the OECD framework has seen notable growth since its inception, with much ongoing research and development, however the P21 framework is more commonly referenced in the literature, especially in studies conducted in the USA.

The Partnership for 21st Century Skills (P21) framework outlines a blend of core subjects, life, and career skills, learning and innovation skills, and information, media, and technology skills. It also emphasises the importance of real-world context in learning (Battelle for Kids, 2019; P21, 2007). Within the P21 framework, the '4Cs' of creativity, critical thinking, communication, and collaboration are featured. The World Economic Forum (2015) produced a similar overarching model of 21st-Century Skills, featuring the 4Cs at the centre, suggesting the importance of these specific skills. The 4Cs have gained considerable attention within education and business (Kelley et al., 2019) and there has since been significant discourse on this aspect of the framework. The 4Cs provide a core concept that is both persuasive and easily targeted, which has been considered a pedagogically and policy-friendly model by large organisations and is also gaining some additional empirical validity (Thornhill-Miller et al., 2023). It is argued that the 4Cs can be seen as the highest-level transversal skills or 'meta-competencies' that allow individuals to maintain proficiency and continue developing their potential in a rapidly changing professional world (ibid.), making the 4Cs a suitable focus for this study.

The issue of skills and knowledge, whether one is more important, and indeed whether one is possible without the other has been debated across education for many years (Christodoulou, 2023). With the current emphasis on knowledge, there is a preference for direct instruction (Stockard et al., 2018). It is argued that direct instruction is best for knowledge transmission, modelling and demonstrating, however, is never sufficient on its own to ensure a deeper understanding of problem-solving, creativity or group work capacities (Desforges, 1995), therefore arguing the case for the enabling of skill development, especially those related to critical thinking. The discourse around skills and knowledge is vast and a lack of clear definitions for 'skill', 'knowledge' and 'competence' adds complexity, yet there is support for the argument that skill can be seen as the ability to retrieve knowledge and apply it to a task in a proficient manner (Lamri & Lubart, 2023). Skill can be conceptualised as "specific know-how that is pertinent to a given situation, resulting in the combination of knowledge" (Lamri & Lubart, 2023, p. 2) and other factors, emphasising that one cannot exist without the other. Skills versus knowledge could also be viewed as a false dichotomy, where knowledge forms the foundation for skill development (Christodoulou, 2023).

In the context of England's educational landscape, there is a notable shift towards a 'knowledge-rich' curriculum, as evidenced by the prominence of the English Baccalaureate (EBacc) in educational policy discourse (McLain et al., 2019). This movement appears to endorse a more traditional, knowledge-centric approach, potentially at the expense of creative and practical aspects of learning (McGarr & Lynch, 2017). The latest GCSE and A Level D&T Programmes of Study (DfE, 2015a, 2015b) reflect this shift, with a narrowed focus on exam-oriented content and less emphasis on creative coursework (Demetriou & Nicholl, 2022). This trend raises concerns about the erosion of D&T's identity (Spendlove, 2023a, 2023b) and its ability to foster a balanced set of skills within the curriculum.

Critics such as Demetriou and Nicholl (2022) argue that this reduced emphasis on imaginative and creative aspects in the curriculum could lead to a corresponding decline in these qualities amongst students. The current trend towards a 'knowledge curriculum', with its focus on academic achievement, presents a challenge to the development of broader human skills that are traditionally nurtured by constructivist and pragmatist educational approaches (Biesta, 2014; Hickman et al., 2009). This shift emphasises the need for a balanced educational model that values both academic knowledge and the development of practical, creative, and human-centred skills (Noweski et al., 2012; Razzouk & Shute, 2012; Scheer et al., 2012) – a balance that D&T is uniquely positioned to provide (Demetriou & Nicholl, 2022).

The D&T curriculum in England is ideally positioned to develop 21st-Century Skills, particularly in tackling contemporary societal challenges (Morrison-Love, 2022), by engaging students in contextual design and real-world problem-solving. While the subject possesses the potential to enable this sort of transformation, there is growing concern about the excessive focus on practical work in D&T at the expense of its educational and creative potential (de Vries, 2005; Nicholl et al., 2013; Nicholl & Spendlove, 2016). This focus contradicts the rigorous and innovative nature of D&T as envisioned in the English National Curriculum (DfE, 2013) and its GCSE and A Level Programmes of Study (DfE, 2015b, 2015a).

While increased subject matter has created challenges for teaching in all subjects in later key stages (Brown & Woods, 2022), it has been established that curriculum design at Key Stage 3 in D&T is a significant issue across England (Design and Technology Association, 2023), which contributes to the threat of continued decline of the subject. Practices have typically become focused on "routine practical tasks masquerading as design and make" (McLain, 2020, p. 79), with a distinct absence of creativity and authentic problem-solving (de Vries, 2005; Demetriou & Nicholl, 2022; Design and Technology Association, 2023; Nicholl et al., 2013; Nicholl & Spendlove, 2016; Rutland & Barlex, 2007), however, it should be noted that this does not apply universally across all schools and classrooms (Design and Technology Association, 2023). This tendency towards a restricted focus impacts the subject in many ways, such as its reputation for being a less rigorous subject (Blom, 2022), its uptake for further study at Key Stage 4 (Spendlove, 2023b) (see Figure 1), and the amount of time and resources allocated to the subject; all contributors to the further decline of the subject (Banks & Williams, 2023; Spendlove, 2023b).

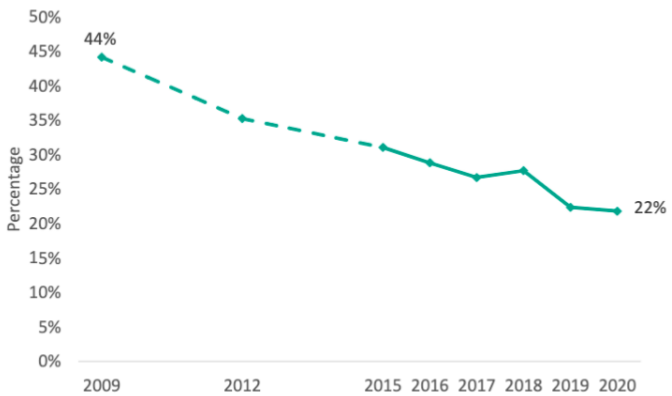

Figure 1 - Percentage of students at the end of key stage 4 entered for at least one Design and Technology GCSE (Tuckett, 2022)

Design Thinking

It is well-established that the design process is non-linear and is in fact a cyclical process (von Mengersen, 2023), however it is argued that teachers often pose learning as predominantly making (McLellan & Nicholl, 2013; Mulberg, 1992; Nicholl & Spendlove, 2016), or treat problem-solving as a series of steps, which does not necessarily affect the students' thinking (McCormick, 2004), therefore they remain in the procedural knowledge space, impeding the development of authentic problem-solving skills (Nicholl et al., 2013; Nicholl & Spendlove, 2016; Demetriou & Nicholl, 2022). As a result of a lack of time and students' understanding of contexts, the design process can be impeded, leading to poorer outcomes (Demetriou & Nicholl, 2022), highlighting the impact of authentic D&T activities. This provides an opportunity to investigate ways in which students engage in design-based research activities which centre around problem-solving.

Design thinking is a concept that gained significant traction over the past decade yet was first introduced as a concept as early as 1987 (Kimbell, 2011), although the term is used to describe two groups of activities, which adds confusion. Design thinking (verb) is thinking as a designer or engaging in professional design activities known as designerly thinking, which was popularised by the work of Nigel Cross (2011). Design Thinking (noun) represents a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test (Interaction Design Foundation, 2023). Design thinking as a methodology has seen the most growth in recent years within the business and management space (Cross, 2023; Razzouk & Shute, 2012), but has also seen significant growth within the design field (Dorst, 2011), and in education (Koh et al., 2015; T. Li & Zhan, 2022; Lor, 2017; Pande & Bharathi, 2020; Park et al., 2023). To ensure clarity, design thinking as a problem-based learning model (Park et al., 2023) was referred to as Design Thinking Integrated Learning (DTIL) by T. Li & Zhan (2022), a term which has also been adopted in this study to avoid confusion with D&T.

The design thinking cycle is particularly suited to dealing with ill-defined and wicked problems as described by Buchanan (1992, as cited in Cross, 2023). The exposure to these sorts of complex, real-world problems is of interest in education because it helps to prepare students to deal with uncertainty and ambiguity (Koh et al., 2015). DTIL is gaining recognition in education (Henriksen et al., 2020), due to its focus on complex problem solving. It is posited that DTIL supports the creation of new knowledge and ideas, but it also contributes to the development of skills in making and doing, as well as dealing with ambiguity, in addition to working and empathising with others (Carroll et al., 2010; Goldman & Zielezinski, 2022; Koh et al., 2015), all valuable skills and competencies required for success in today's world. The facilitation of DTIL contributes to the holistic development of children and is particularly relevant to education in schools, therefore this methodology, especially in its relation to 21st-Century Skill development, is of interest. The implementation of DTIL in K-12 education has indicated an upward trend, as evidenced by recent systematic literature reviews (Li & Zhan, 2022; Rusmann & Ejsing-Duun, 2022), with a notable surge in publications post-2017. However, the application of DTIL as a design-based methodology within educational curricula can be complex, given global variations in design education, the emphasis on STEM, and an emphasis on interdisciplinary learning. Despite these challenges, DTIL is increasingly viewed as a crucial means to develop 21st-Century competencies.

Current research on the implementation of DTIL in schools is still developing, along with the necessary tools and strategies for its effective integration (Gardner, 2008; Koh et al., 2015; Öztürk & Korkut, 2023; Rusmann & Ejsing-Duun, 2022; Yeung & Ng, 2023). Therefore, this study seeks to contribute to this emerging area of research, particularly within the primary and secondary education contexts where there is a gap in the literature (Li & Zhan, 2022), and aims to demonstrate how DTIL can be effectively utilised to enhance the learning experience and skill development of these younger students.

There are more than twelve design thinking models available (Liu et al., 2024), which educators use to facilitate students' engagement with the design thinking process and to enhance their understanding of its core principles (T. Li & Zhan, 2022). Typical models, such as the IDEO process model (Discovery, Interpretation, Ideation, Experimentation, and Evolution) (IDEO, 2012), the Stanford d.school's five iterative stages (Empathize, Define, Ideate, Prototype, Test) (Hasso Plattner Institute of Design at Stanford University, 2018) and the Double Diamond model (Discover, Define, Develop and Deliver) (Design Council, 2005), have been adopted in primary and secondary education (Li & Zhan, 2022). The five stage process developed by the Stanford d.school was utilised in this study, due to its prevalence in the literature concerning design thinking integration within education.

Design thinking fundamentally employs a unique form of reasoning known as 'abductive' reasoning, distinct from traditional deductive and inductive logic (Kolko, 2010). Deductive reasoning operates from a general-to-specific framework, determining what necessarily must be true, while inductive reasoning moves from specific observations to broader generalisations, focusing on what actually is (Rao et al., 2022). Abductive reasoning, in contrast, concerns exploring possibilities as opposed to asserting truth, which forms the centre of DTIL, and within the realm of design more generally (Lawson, 1997). Reasoning within DTIL does not aim to declare a conclusion as definitively true or false but instead seeks to uncover a range of potential outcomes or scenarios. This mode of thinking is essential in DTIL (Rao et al., 2022) as it allows for the consideration of various possibilities and innovative solutions that may not be immediately apparent through conventional logical approaches, thus making DTIL a valuable pedagogical model, particularly for equipping students with skills that would enable them to cope with 21st-Century demands (Retna, 2016), and potentially serving as a "model of thinking" for the contemporary student (Y. Li et al., 2019, p. 94).

D&T education offers a unique combination of disciplinary knowledge and practical application, fostering an environment where students can engage in hands-on learning and creative problem-solving (von Mengersen, 2023). This approach enhances their understanding of design principles and providing them with the necessary skills to drive innovation and adaptability (Blom, 2022). D&T embraces an interdisciplinary approach, integrating aspects of predominately design, and technology, but also science, arts, and humanities (McLain et al., 2019). This broadens students' perspectives, allowing them to apply their skills in various contexts and encouraging them to challenge conventional paradigms (McLain, 2023). In essence, D&T education is focused on cultivating an innovative approach, creativity, and adaptability, through the signature pedagogies of designing, making, and critiquing (McLain, 2020, 2022, 2023). These are the diverse set of skills that will enable students to thrive in the 21st-Century (Razzouk & Shute, 2012), thus establishing design education as a crucial element of early general education to produce rounded and successful members of society (Barlex & Steeg, 2017; Beaumont & Steeg, 2024).

Methodology

Participants

While n=160 students were exposed to this curriculum intervention, a sample of four participant groups were randomly chosen for this study and ethical approval granted by Liverpool John Moores University. A total of n=16 participants worked in teams of four with each group belonging to a different class. All participants are aged 12-13 years (Year 8). Year 8 was selected as the curriculum year group for this intervention because students are mid-way through their Key Stage 3 D&T study. Year 7 students at the focus school arrive from over fifty different primary schools, therefore students begin secondary education with varying experiences of D&T at primary level, and with this, varying levels of expertise and knowledge. By the end of Year 7, there is some parity in the knowledge and skills of the students due to the curriculum they experience, therefore Year 8 presents as a more appropriate stage to conduct such an intervention. A constructivist intervention such as DTIL requires a foundation knowledge on which to build upon, and as Ausubel (1968) posits, the most important factor that influences learning is what the learner already knows; new knowledge is therefore interpreted and then connected to existing knowledge (Dennick, 2016). Without this foundation knowledge, students would be unable to deepen their understanding of established concepts, thus reducing the quality of learning outcomes during the intervention. This foundation is afforded in Year 7 D&T, providing the conditions required in Year 8 to successfully build on this, while offering more freedom in the process.

Intervention Structure

The intervention spanned twelve 55-minute weekly lessons, including homework tasks between sessions. Although delivered to ten classes through forty different contexts, the structure remained consistent.

Observe and Empathise Phases (Sessions 1-2)

Session 1: Students watched a video on design thinking (Belfast Met, 2022), learned about effective interviewing, empathising, and communication techniques, and viewed a video of a chef's experience to build empathy. They created problem statements starting with "how might we…" (Lewrick et al., 2020).

Session 2: Students visited end-users, documented observations, and developed problem statements as design briefs. They reflected on their feelings, observations, and problem-solving strategies in their journals.

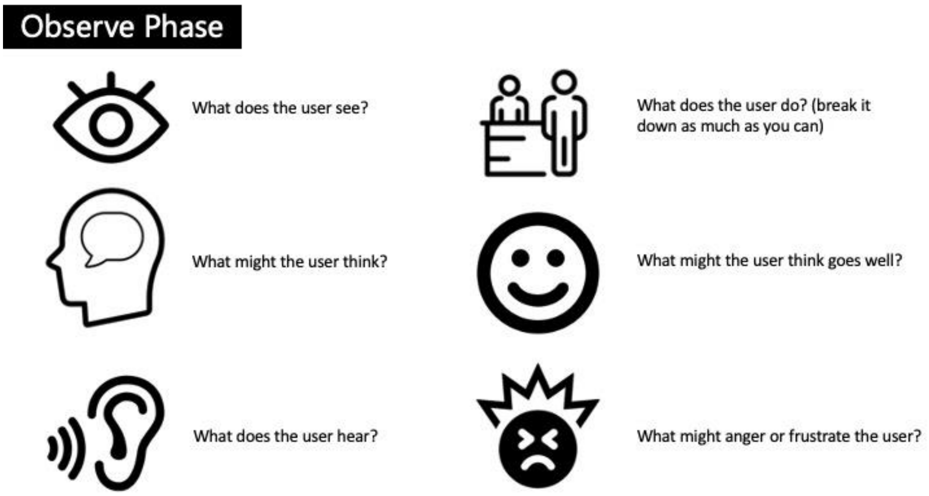

Figure 2 - Observe Phase Activity

Ideation Phase (Session 3)

Students converted circles into objects based on an activity by T. Kelley & Kelley (2013), discussed creativity, and generated 40 ideas in 15 minutes using coloured post-it notes. Ideas were reviewed using an adapted dot-voting activity (Goldman & Zielezinski, 2022). Reflective journals focused on the ease of idea generation and user feedback.

Figure 3 – Example of a range of ideas generated during this session.

Prototyping Phase (Sessions 4-10)

Session 4: Students shared ideas with end-users, developed concepts using card modelling and 3D CAD (Shapr3D), and gathered feedback.

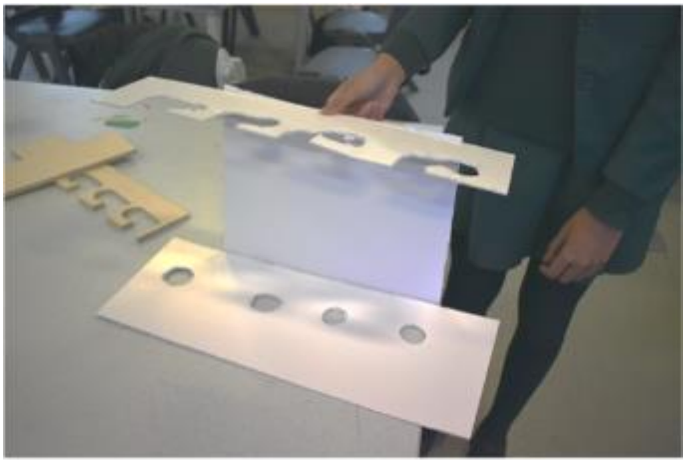

Figure 4 - Example of a foam board model produced during this session.

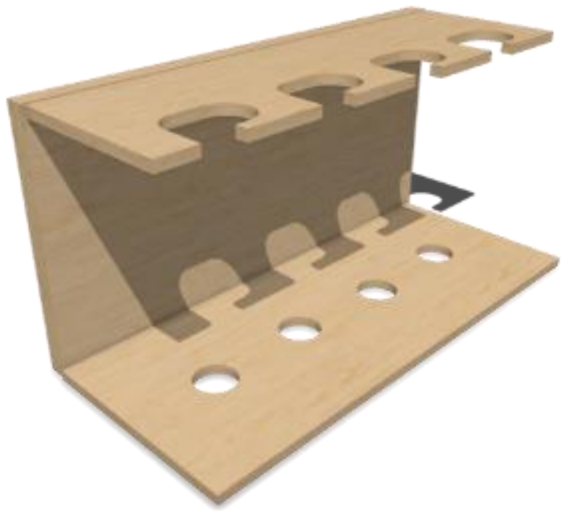

Figure 5 - Example of a 3D CAD model produced during this session.

Session 5: Technical considerations were addressed, including materials, components, and manufacturing processes.

Sessions 6-10: Students focused on product manufacturing, reflecting on tools used, accuracy, teamwork, and learning needs.

Consolidation Task (Session 10)

Students considered how their D&T knowledge had developed by using the ‘Big Ideas for D&T’ as a framework (Barlex & Steeg, 2017; Beaumont & Steeg, 2024) as part of presentation planning.

Testing Phase (Session 11-12)

Students presented products to end-users, conducted tests, and began planning their final presentations. Reflective journals assessed product success, construction quality, and team effectiveness. Students presented their design process orally to their class.

Methods

There is an increasing necessity to assess 21st-Century Skills (Voogt & Roblin, 2012) using a variety of tools instead of traditional tests (Geisinger, 2016; Miliou et al., 2023), with a movement towards adopting assessment strategies centred around self-assessment and reflection (Care & Kim, 2018; Miliou et al., 2023) as a more comprehensive way of assessing 21st-Century Skills. There are calls for a wider variety of assessment instruments (Greenstein, 2012; P21, 2007), for example, performance-based assessments, rubrics, portfolios, and peer and self-assessment, to provide a more comprehensive perspective on 21st-Century Skill development (Foster & Piacentini, 2023).

Performance-Based Assessments (PBA) involve tasks that require students to apply their skills in real-world or simulated scenarios, making them suitable for evaluating 21st-Century Skills (Stanley, 2021). PBA appraises students on items such as portfolios, projects, and writing samples, and provides teachers with the opportunity to give more nuanced feedback compared to traditional testing (ibid.). Rubrics are often used to assess performance; clear criteria for 21st-Century Skills can offer detailed descriptors for different skill levels, focusing on both the process and product of learning activities (Barnes et al., 2022), with well-written rubrics clarifying for students the expectations of the assessment and acting as a framework for students to use, and also increasing student motivation (Zhao et al., 2021). Rubrics can enhance consistency in assessment between teachers (Stanley, 2021), however, while rubrics are effectively used for assessing knowledge, they can be more difficult to use in the measurement of growth in relation to 21st-Century Skills (Kelley et al., 2019), although remain a useful way of assessing skills when students engage with DTIL specifically (Goldman & Zielezinski, 2022; Taheri et al., 2016).

Digital portfolios are another popular assessment method for 21st-Century Skills. They allow students to showcase their work and reflections over time, offering insights into their skill development (Shively et al., 2018). Portfolios can include various works, providing a comprehensive view of students' application of 21st-Century Skills (Greenstein, 2012). This intervention requires students to keep an online portfolio for reflections, which is also used to support their summary presentation at the end of the project.

Peer and self-assessments capture interpersonal and intrapersonal skills like collaboration, communication, and self-regulation, promoting reflective learning (Andrade & Valtcheva, 2009). An example of a self-reporting tool to assess the 4Cs in high school students is the ‘21st Century Instrument’ (Kelley et al., 2019), which provides a framework for students to evaluate their own proficiency in these areas, reflecting on their perceptions of their skills in critical thinking, creativity, collaboration, and communication. A student survey is a useful instrument for educational researchers and educators seeking to monitor and promote the students’ abilities in 21st-Century Skills, however there are very few self-reporting instruments for measuring 21st-Century Skills holistically (ibid.), as most typically focus on a particular aspect, such as creativity (Demetriou & Nicholl, 2022; OECD, 2019a).

There is advocacy by the OECD for designing long-term units of learning whereby students are allowed to be creative (Foster & Piacentini, 2023). The design of products is an example given, which provides “low floors, high ceilings” (ibid., p. 29), allowing the weakest and strongest of students to succeed and develop their 21st-Century Skills. A longer unit of work provides more opportunities to assess skills using a variety of methods, which is especially useful when situated in a domain specific context where disciplinary knowledge may be assessed more traditionally, alongside the other assessment instruments.

To assess the development of 21st-Century Skills alongside subject-specific knowledge, a mixed methods approach was adopted. The selected methods included the ‘21st Century Instrument’ developed by T. R. Kelley et al. (2019), administered both before and after the intervention, as well as student work, reflections, and presentation audio recordings. Mean point scores were used to analyse the intervention's impact on participants’ self-reflections. Additionally, a rubric inspired by the Big Ideas for D&T (Barlex & Steeg, 2017; Beaumont & Steeg, 2024), shown in Table 1, was developed as a framework for mapping areas of knowledge and assessing mastery. It should be noted that this rubric's scope covers the entirety of Key Stage 3 (and beyond), and this curriculum intervention alone would not adequately cover all criteria in depth.

There is clear overlap in some of the D&T knowledge-based criteria and 21st-Century Skills, such as ‘critical thinking and innovation’ and ‘reflection and adaptability,’ which are considered D&T knowledge rather than skills in this context. A second rubric, the ‘21st Century Learning Design Student Work Rubric’ developed by SRI International (2012) in collaboration with Microsoft, was adapted to assess the extent to which participant teams developed their 21st-Century Skills across four of its six areas: collaboration, knowledge construction (critical thinking), real-world problem-solving and innovation (creativity), and skilled communication. These rubrics were shared with students before the intervention to support and frame their learning.

Table 1 – Rubric used to assess learning during intervention.

Conceptual Understanding and Application	
Developing	Basic grasp of material properties, maths, and science integration, and an introductory understanding of historical impacts and market opportunities.
Secure	Solid application of concepts to design projects with an understanding of historical contexts and ability to identify market opportunities.
Excellent	Demonstrates advanced integration of interdisciplinary knowledge, utilising a deep understanding of materials, scientific principles, historical insights, and market trends to develop innovative designs.
Critical Thinking and Innovation	
Developing	Begins to apply creative thinking and problem-solving in design projects, exploring multiple solutions with some understanding of their potential impact.
Secure	Employs critical analysis and creativity to develop innovative and effective design solutions, considering a broad range of possibilities and implications.
Excellent	Exhibits exceptional innovation in design, pushing boundaries with original solutions and sophisticated problem-solving that anticipates future trends and challenges.
Ethical Consideration and Social Impact	

Developing	Recognises the importance of designing for inclusivity, sustainability, and social justice, with initial steps towards ethical considerations in design decisions.
Secure	Integrates ethical considerations deeply into the design process, aiming for solutions that address social justice, environmental stewardship, and inclusivity.
Excellent	Generates designs that consider deeply ethical practices, sustainability, and social impact, demonstrating a commitment to advancing societal and environmental well-being.
Reflection and Adaptability	
Developing	Shows basic reflection on design choices and some responsiveness to feedback and unintended consequences.
Secure	Actively seeks feedback, demonstrates adaptability in design revisions, and considers a wide range of impacts and feedback loops in the iterative design process.
Excellent	Exemplifies a reflective and adaptive design approach, using feedback and critical evaluation to refine and evolve designs continually. Demonstrates foresight in anticipating consequences and integrates learning into future innovation.

Findings

Examinations Officer

Students met with the school's Examinations Officer to explore the challenges she encounters in her role. A significant aspect of her duties includes the transportation of exam papers from a secure storage area in her office to the examination hall, located on the opposite side of the school. The students discovered that the Examinations Officer relied on a commercially purchased plastic trolley for this task. However, they noted that the trolley was difficult to manoeuvre, lacked stability and security when unfolded, and caused the exam papers to become jumbled and difficult to access, given the number of different qualifications being examined during the same session.

Individually and then collectively, students formulated the following problem statement to guide their investigations and design work, as well as to establish criteria for evaluating success: "How might we develop a way to transport exam papers easily and securely, while dividing them according to the specific exam?"

Figure 6 – Photograph of the practical outcome from the 'exams' team.

The validated self-assessed instrument used before and after the intervention (Kelley et al., 2019) contained n=30 questions that were grouped to each of the 4C's. Students were asked to what degree they agreed with each statement using a four-point Likert scale. Four-point as opposed to five was chosen to force choice (Chyung et al., 2017) and avoid respondents remaining in the mid-points of the scale. Figure 4 shows the mean scores, alongside a teacher assessed score based on the rubric to assess student work for 21st-Century Skills (SRI International, 2012).

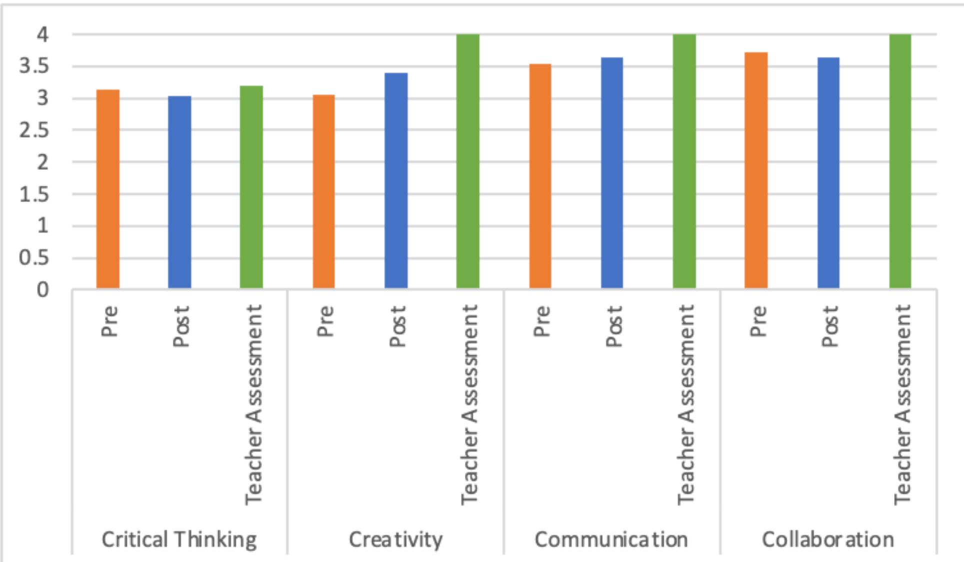

Figure 7 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score.

Cooking and Nutrition Teacher

Students engaged with one of the school's cooking and nutrition teachers and students participating in cooking classes to identify challenges encountered in this context. They learned that laundry management posed difficulties both for the teacher and the students. Used kitchen linens were collected in a laundry basket, cleaned daily by the school's Housekeeper, and returned in a large bag. The teacher was responsible for storing these items in a cupboard, which became a point of congestion during lessons as students needed access to clean tea towels and oven mitts.

Students individually and then collectively formulated the following problem statement to guide their investigations, design work, and to establish criteria for evaluating success:

> *"How might we keep the laundry organised for the students so that cooking is safer and easier? We are restrained by space and the students misusing our product."*

Figure 8 - Photograph of the practical outcome from the 'laundry' team.

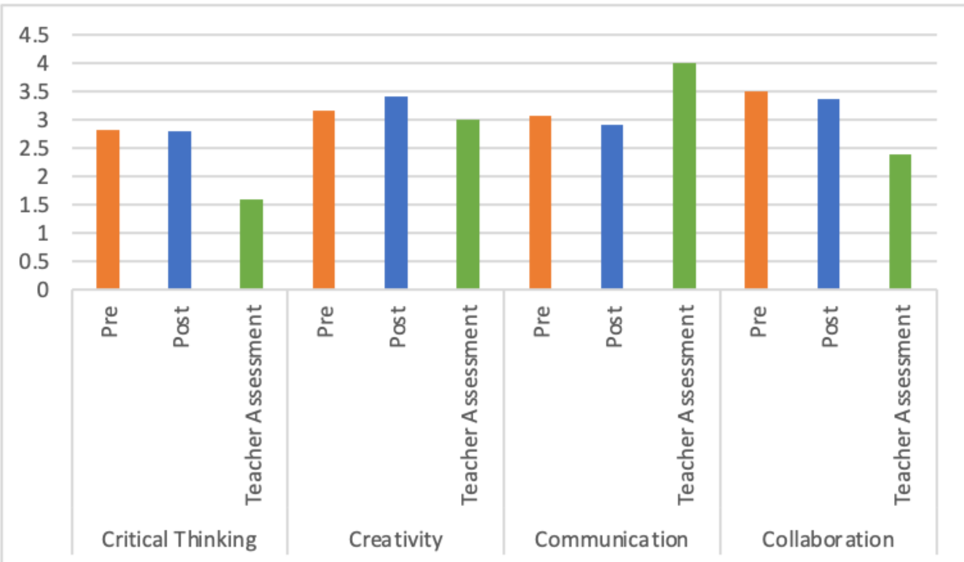

Figure 9 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score.

Housekeeper

Students consulted with the school's housekeeper to identify challenges she encountered in her role. As the manager of the cleaning staff, she is responsible for ensuring the school's cleanliness meets high standards and adheres to Health and Safety regulations. The students discovered an issue with the storage of used mops; they were kept upside down in a large bin, causing the mop heads to touch. The housekeeper highlighted that this storage method was unsuitable due to the risk of cross-contamination and required a better storage solution.

Students individually and then collectively formulated the following problem statement:

> *"How might we make sure that the mops are kept tidy and out of the way so that people won't get hurt by them, as well as ensuring they are separated? We are restrained by space and the size of the mops."*

Figure 10 - Photograph of the practical outcome from the 'laundry' team.

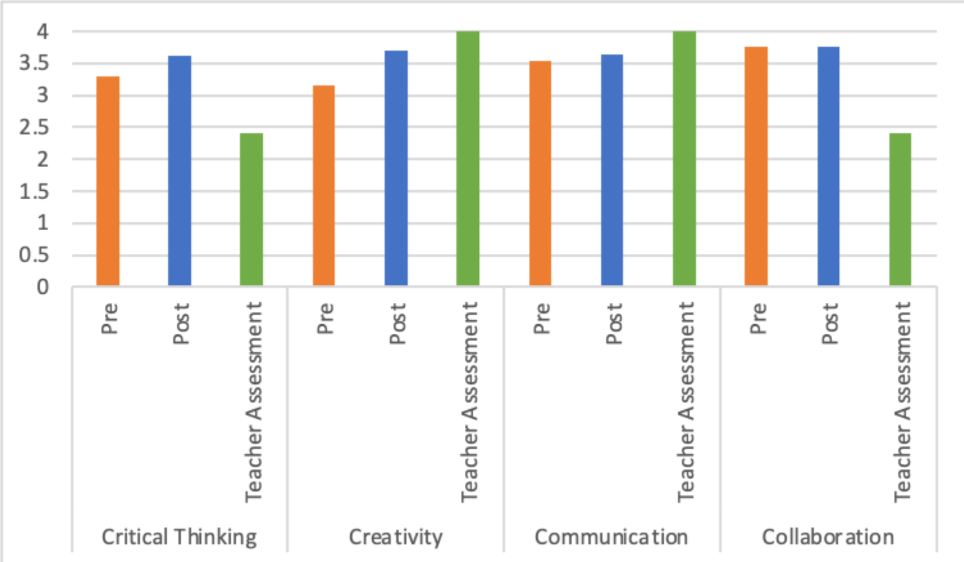

Figure 11 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score.

Music Teacher

Students engaged with one of the school's music teachers to identify challenges within the Music Department. Through their inquiry, they learned that the weekly transport of hymn sheets and Order of Mass cards to the local church posed significant difficulties. The task involved students manually carrying bulky and heavy boxes across a busy road, presenting concerns related to both health and safety and practicality.

Students individually and then collectively formulated the following problem statement:

> *"How might we develop a way to transport hymn sheets and Order of Mass cards between the school and St. Joseph's church in a more efficient and safe manner? We are restrained by the number of cards and their size."*

Figure 12 - Photograph of the practical outcome from the 'mass cards' team.

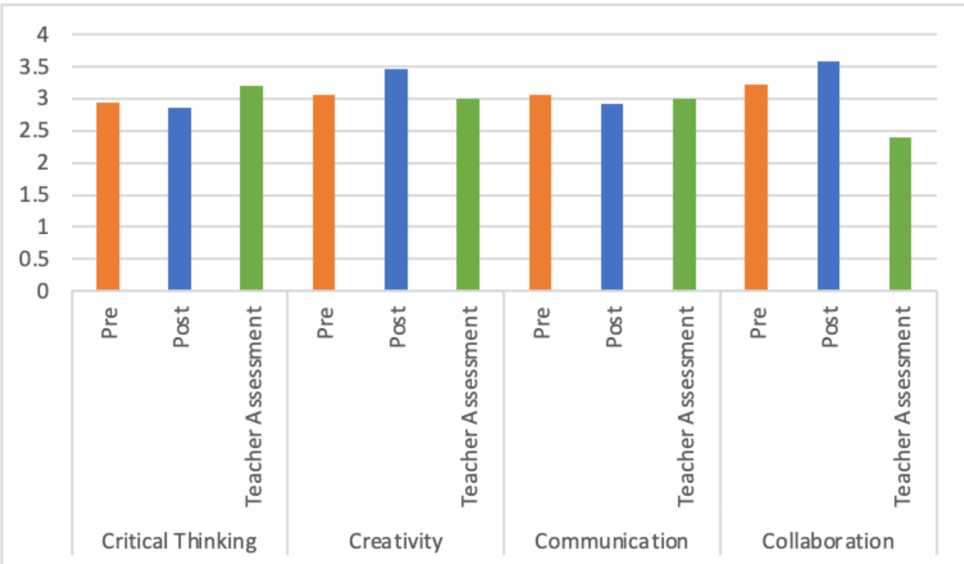

Figure 13 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score

Discussion

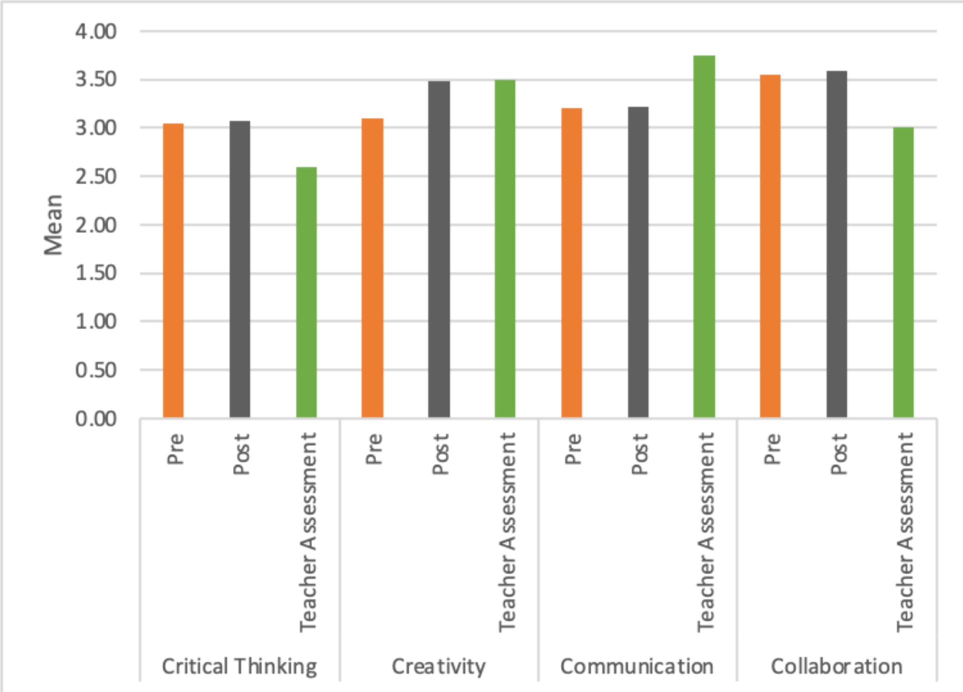

Figure 14 - Mean scores of student perceptions of their 4C skills before and after the intervention for all participants, as well as teacher assessment using rubric.

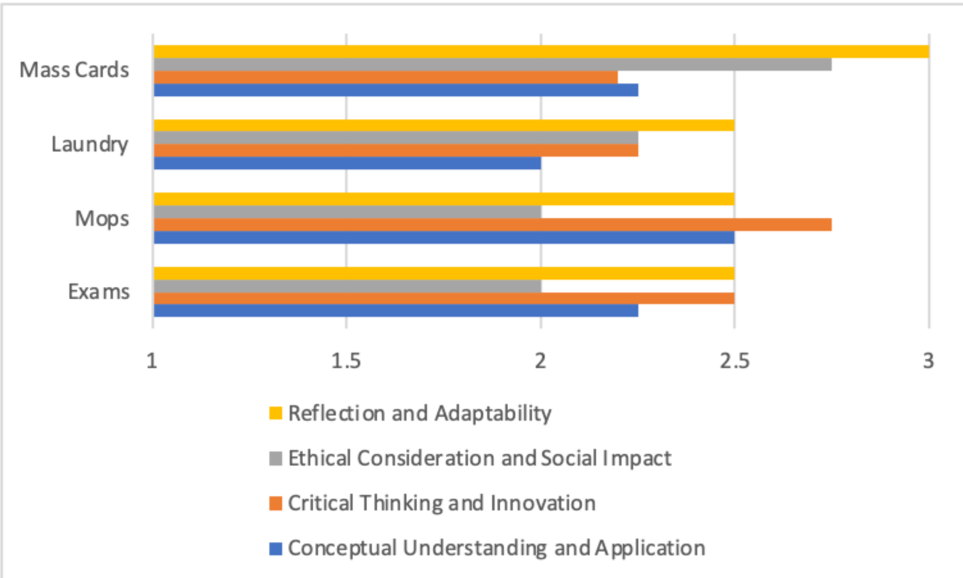

Figure 15 – Mean scores of teacher assessments of D&T knowledge, ranging from 1 (developing) to 3 (excellent) as detailed in Table 1.

Figure 15 illustrates an increase in mean scores across all 4Cs following the intervention, as measured by the self-assessment instrument. However, these increases are generally marginal, with the notable exception of creativity, which shows a more significant improvement. This finding is further supported by the teacher's assessment of creativity.

It is widely acknowledged that when individuals face a problem, they often automatically apply strategies that have proven effective in similar or analogous situations they have previously encountered (Thornhill-Miller et al., 2023). The innovative nature of this curriculum approach introduced students to many novel situations, prompting them to develop new approaches and experiences. This process significantly enhanced their skills across the 4Cs, with a particular emphasis on creativity.

Contrary to traditional views, it is argued that creativity is not an innate trait but a skill that can be cultivated (Nicholl and Spendlove, 2016; Thornhill-Miller et al., 2023), which is supported by the data from this study. It is believed that creativity can be actively taught through direct instruction in creative methods and concepts, as well as indirectly fostered by creating environments conducive to creativity (Chiu, 2015; Thornhill-Miller and Dupont, 2016). Creativity, sharing certain underlying mechanisms with intelligence (Spendlove, 2011), is increasingly acknowledged as a vital skill for adaptability and problem-solving in complex situations (Sternberg, 1986; Craft, 2005), therefore highlighting its importance in a 21st-Century context.

Creativity has become recognised as a crucial skill in the global educational landscape. It operates outside of traditional academic boundaries, playing a critical role in students' ability to innovate, adapt, and solve complex problems in a rapidly changing world (Robinson, 2006; Weisberg, 2006). Creativity in the 21st-Century context transcends artistic expression, enabling the ability to think critically and innovatively, and apply knowledge in new ways (Shaheen, 2010), emphasising the crossover of the 4Cs. It is increasingly recognised as a key component of education, vital for success in diverse fields ranging from technology to business (Craft, 2005). Creative thinking can be viewed as a tangible competence, grounded in knowledge and practice while offering flexibility and adaptability, which supports individuals in achieving better outcomes, often in constrained and challenging environments (Sternberg, 1986; OECD, 2019a), which further highlights its importance for the future. Organisations and societies around the world increasingly depend on innovation and knowledge creation to address emerging challenges (OECD, 2010), placing emphasis on innovation and creative thinking collectively.

Educators face the challenge of creating learning environments that encourage risk-taking and original thinking while still ensuring mastery of essential content (Robinson, 2006). There is increasing evidence that educational practices are incorporating project-based learning, inquiry-based learning, and collaborative tasks that foster creative thinking and problem-solving skills (Bell, 2010), alongside the development of subject knowledge, which encourages students to explore, experiment, and engage with content in innovative ways, which are crucial for developing creativity (Craft, 2005; Klapwijk, 2017). While creativity necessitates freedom and flexibility, it also thrives on deep subject knowledge (Weisberg, 2006), demanding a balance. This is more challenging in areas where traditional curricula focus heavily on rote learning and standardised testing (Zhao, 2012), which is the current trend in England with its knowledge-centric curriculum (Bell et al., 2017; McLain et al., 2019). Though small-scale, this study highlights that there was success in integrating a constructivist approach to problem-solving, which enhanced 21st-Century Skills alongside subject specific knowledge. The study established that in order to be creative with design and practical work, capability was predicated on prior knowledge and experience. In the time constraints of this project, the student outcomes they produced would not have been possible by introducing concepts for the first time; therefore, students were required to draw on prior knowledge and build on this socially, with assistance from their peers and teachers, a key component of constructivism, particularly constructionism (Papert, 1980).

Communication inherently connects with the other 3Cs. In relation to critical thinking, effective communication fosters an environment conducive to goal-oriented, realistic exchanges (Griffin & Care, 2015; Trilling & Fadel, 2009). It is closely linked to collaboration, as successful teamwork relies heavily on quality knowledge sharing and the trust that develops among group members (Johnson & Johnson, 2009). Furthermore, creativity in communication is particularly evident when ideas are conveyed to an audience or during collaborative creative endeavours. The data from this investigation suggests that students tended to rate their communication skills lower than that of the teacher, possibly indicating that the self-assessment of communication did not correlate with the teacher assessment rubric or that students did not have confidence in their communication abilities. Communication during this curriculum project was essential in all activities, including face-to-face collaboration, working with end-users, presenting to peers, and visually through sketching, modelling, and writing, as well as during practical activities. This intervention provided a wide range of opportunities for communication skills, and associated knowledge to be developed.

Limitations of the Study

This study is limited in scale, which precludes the generalisation of its findings. Additionally, a further limitation is the use of broad instruments; a more focused examination of knowledge and skill acquisition in specific areas could yield a more nuanced understanding of how DTIL can support learning, rather than the broader approach taken in this study. Employing a more analytical method, such as content analysis of student work, could lead to a better understanding of how different contexts impact learning, especially on an individual student level, given that some analyses in this study focused on group assessments.

Employing the knowledge rubric as a standard assessment tool across the Key Stage could have supported pre- and post-intervention analysis to more accurately assess its impact. Adopting a more comprehensive approach to analysing data from the self-assessment instrument, such as using standard deviations and paired sample t-tests, could have identified whether the gains were statistically significant, thereby providing a clearer understanding of skill development and the effectiveness of the curriculum design.

Additionally, the effectiveness of the curriculum design itself was not evaluated in this study; further exploration in this area would be beneficial. Similar to the '21st Century Learning Design Student Work Rubric' developed by SRI International (2012), the organisation also published the '21CLD Learning Activity Rubrics' (SRI International, 2012), a framework for assessing the effectiveness of learning activities, which could have contributed to the development of a more effective curriculum design. Incorporating additional methods, such as focus groups or interviews, could provide a richer dataset to analyse the impact of this intervention.

Implications of the Study

While this small-scale study highlights a range of fruitful outcomes and makes some progress in establishing that this curriculum intervention supports the development of 21st-Century Skills alongside knowledge, there is an opportunity to further capitalise on developing core subject knowledge, such as the inclusion of electronic or mechanical systems. In future iterations of this intervention, students could be required to consider key aspects of the curriculum to satisfy knowledge progression, in addition to human skills. A disadvantage of prioritising specific subject content to ensure adequate delivery is that the authentic problem-solving element of this project could be compromised, making design activities contrived.

The inclusion of users from outside of the school, for instance in the community or in industry could enhance this intervention and potentially improve the development of 21st-Century Skills. The careful selection of contexts to enable sufficient coverage of subject content would be imperative. An example of an upcoming project with Year 8 students which is more constrained involves input from an audiologist at a local hospital. There have been strict cleanliness rules established since the COVID-19 pandemic, consequently a child-centred product used during paediatric hearing tests can no longer be used, requiring a new solution made entirely of polymers. This project has the potential to include many areas of D&T subject content, including systems, but will require teachers to teach more specifically about polymers and manufacturing from this material. On the one hand, students are more likely to develop a deeper knowledge of polymers due to the context, yet this could potentially limit the development of knowledge of a wider variety of materials.

Conclusion

This study conducted at Key Stage 3 in D&T offers insight into DTIL and its impact on fostering 21st-Century Skills alongside subject-specific knowledge. The DTIL approach, implemented through a structured intervention, has demonstrated its effectiveness in engaging students in real-world problem-solving tasks that enhance their creativity, collaboration, communication, and critical thinking skills. By departing from traditional pedagogies within D&T and embracing Design Thinking, the findings highlight the potential of an innovative curriculum framework in preparing students for the complexities of modern life and work.

The study also identifies significant challenges, primarily the existing educational emphasis on knowledge acquisition over skill development within the English curriculum. This emphasis potentially undermines the creative and practical dimensions of learning that are crucial for students to thrive in a 21st-Century context. The research illustrates a need for educational policies and curricula that balance subject knowledge with human skills, ensuring that education is comprehensive and relevant, emphasising the role that D&T can play in general education.

In conclusion, this study contributes to the ongoing discourse on reform in D&T by providing some evidence of the benefits of integrating 21st-Century Skills and Design Thinking into the curriculum. Moving forward, it will be necessary to expand this research to larger and more diverse populations to further validate and refine the DTIL model, along with the refinement of instruments to measure its impact.

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29.2

Empowering learning through integration: Enhancing understanding of variables and functions in the context of STEM education

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Abstract
This paper explores the integration of STEM activities in teaching and learning, emphasizing the importance of innovative pedagogical approaches in effectively introducing theoretical concepts, such as variables and functions, and merging them with practical applications. Drawing on existing literature, this study investigates the integration of STEM activities with real-world applications to enhance mathematics learning, highlighting intrinsic motivation, self-efficacy beliefs, and goal orientation as key factors in fostering student engagement. This case study explores the integration of a STEM activity to introduce students to variables and functions through a pendulum experiment. The aim is to demonstrate the impact of this approach on students' understanding of abstract mathematical concepts, as well as their problem-solving skills. By combining cognitive and social constructivism with technological modes (virtual labs), the study showcases the transformative potential of innovative techniques in STEM education. The outcomes of the study highlight, to some extent, the positive effects of STEM activities on students' engagement, motivation, understanding of theoretical concepts, and problem-solving skills. The focus on hands-on activities supports practical learning experiences and fosters critical thinking. Additionally, virtual labs enrich students' exploration of complex mathematical phenomena, enhancing their ability to apply prior knowledge to new contexts and transcend the boundaries of traditional lab settings. Overall, the findings underscore the transformative potential of innovative pedagogical approaches and technological modes in creating engaging learning environments within STEM disciplines.

Keywords
STEM activities, variables and functions, motivation, pendulum motion.

Introduction
In today's educational landscape, the integration of STEM (Science, Technology, Engineering, and Mathematics) has become paramount in shaping effective teaching and learning practices, especially in mathematics and science classrooms. This study explores the critical role of STEM in helping students not only understand variables and functions in mathematics, but also prepare them for the challenges of a rapidly evolving world. Building on the foundational work of scholars such as Bybee (2011) and Rocard et al. (2007), this article goes even deeper into the integration of STEM in mathematical context in a rapidly evolving world. Moreover, we further explore how inquiry-based learning methods can enhance critical thinking skills and enable primary students to make interdisciplinary connections crucial for real-world problem-solving (Hmelo-Silver, 2004). By examining key principles and strategies in these domains, we uncover

the transformative impact they have on enhancing student engagement, promoting critical thinking, and nurturing a future-ready mindset.

Literature Review

Teaching Variables and Functions

Teaching variables and functions is crucial for developing students' mathematical proficiency and problem-solving skills. By understanding the benefits and challenges associated with these concepts, teachers can enhance the learning experience and support students' mathematical growth. Why are teaching variables and functions is so important? According to Smith & Thompson (2018), introducing variables and functions helps students develop a deep conceptual understanding of mathematical concepts. They learn to connect abstract ideas with real-world applications, enhancing their problem-solving abilities.

Moreover, working with variables and functions encourages students to think critically and analytically. They learn to analyze relationships, make connections, and apply mathematical reasoning to solve complex problems (Boaler, 2016). Beside that, mastering variables and functions prepare student for advanced mathematics such as algebra, calculus, and statistics. Students who master these concepts are better prepared for higher-level math courses (Schoenfeld, 2016). Additionally, Stacey & Turner (2014) highlight that variables and functions are extensively used in various fields, including science, engineering, and computer science. Teaching these concepts equips students with skills applicable in real-world scenarios and professional domains.

However, teaching variables and functions can be too abstract for some students, posing initial challenges in comprehension. To address this, educators should use concrete examples and visual representations to make these concepts more accessible (Burns & Hattie, 2019). Similarly, the interplay between variables and functions can be complex for students, especially when it comes to understanding domain and range, function transformations, and inverse functions (Cai & Leikin, 2020). Many other scholars highlight that students may develop misconceptions or incorrect interpretations of variables and functions. Addressing these misconceptions requires targeted instruction, formative assessment, and opportunities for corrective feedback (Hiebert & Grouws, 2007). Under these circumstances, teachers should commit wholeheartedly to the success of all students by adapting their teaching methods to accommodate diverse learning needs. Meeting these needs, especially for students requiring additional support, can be challenging. However, employing differentiated instruction strategies, such as traditional labs and virtual labs, can help address this challenge effectively (Tomlinson, 2017).

Comprehensive Concerns in STEM Education

In our analysis of educational literature, we explored various justifications put forth by scholars advocating for the integration of STEM education into secondary schools. The review revealed a diverse range of reasons supporting the adoption of STEM initiatives. In light of this review, we noticed that scholars categorize their justifications into five distinct groups that significantly influence pedagogical strategies and impact student learning outcomes. These concerns extend across epistemological, curricular, procedural, motivational, and technological dimensions, highlighting their shared significance and influence in these educational domains.

Epistemological Concern

In the context of STEM education, epistemology refers to the study of how knowledge is acquired, constructed, and applied within the fields of STEM (Duschl et al., 2007). It emphasizes the effectiveness of STEM epistemic practices, which can help students acquire new knowledge through activities such as investigating processes, sense-making, and critiquing (Bevan et al., 2019; Fortus et al., 2004). These practices are essential for students to develop a deep understanding of the nature of science and the processes involved in STEM disciplines. Among the investigative processes, inquiry-based learning and the Technological Design Process (TDP) deserve special attention as they play a significant role in facilitating students' acquisition and application of new knowledge across diverse fields for problem-solving in the science and engineering context (Rocard et al., 2007). By engaging in these processes, students actively inquire, leading to a deeper understanding of mathematical, scientific, and engineering concepts, and facilitating the transfer of knowledge.

The work of Bybee (2011) and Rocard et al. (2007) discuss how investigative processes enable students to explore scientific phenomena, design artifacts, conduct experiments, analyze data, and draw conclusions. Through these processes, students actively construct knowledge, demonstrating the central focus of epistemology. Additionally, Hmelo-Silver (2004) supports this notion by affirming that inquiry-based learning and TDP enhance critical thinking skills, enabling students to evaluate evidence and make interdisciplinary connections crucial for real-world problem-solving. By transcending rote learning, these investigating processes promote a profound understanding of scientific, mathematical, and engineering concepts, aligning with the core principles of epistemology. They encourage students to actively engage in learning experiences, fostering a passion for knowledge acquisition.

Curricular Concern

Our study aligns with the principles outlined in various studies and curricula around the world. It suggests that the integration of STEM education can effectively enhance traditional subject areas, requiring a clear distinction between STEM skills and disciplinary knowledge. By embracing the interdisciplinary nature of STEM, educators can foster a deeper understanding of core concepts while promoting critical thinking, problem-solving, and collaboration among students (National Research Council, 2012; Ontario curriculum, 2022). The integration of STEM education in schools has significant implications for the curriculum, necessitating a thoughtful consideration of its interactions with other disciplines. Tytler (2020) highlights the importance of differentiating STEM skills from disciplinary knowledge, recognizing the unique contributions and challenges that STEM education brings. Moreover, STEM education plays a critical role in cultivating essential skills needed for the twenty-first century and preparing students for a job market that increasingly demands STEM expertise (Tipmontiane & Williams, 2022).

In addition to the broader context of STEM education, Technology Education (TE), the subject used in the Quebec context to teach STEM, faces specific learning challenges that require attention within the curriculum. These challenges include effectively integrating practical activities with theoretical concepts from various disciplines and adapting to the ever-evolving landscape of technological advancements (Dugger, 2009, El Fadil et al., 2018). Since the publication of the Standards for Technological Literacy (ITEA, 2007), the introduction of STEM education has further disrupted traditional subject areas, necessitating not only a clear distinction between STEM skills and disciplinary knowledge but also potential interactions between these disciplines. These interactions are crucial in preparing students for STEM-focused careers and ensuring that they possess the necessary skills and competencies to thrive in a rapidly changing world (National Research Council, 2011).

By addressing these curricular aspects, educators can navigate the disruptions caused by the integration of STEM education and leverage its potential to enhance student learning experiences. It requires a deliberate and intentional approach to curriculum design that incorporates STEM skills, while also providing a solid foundation in disciplinary knowledge. Through this balanced integration, schools can prepare students to excel in the interdisciplinary nature of STEM fields and equip them with the skills and knowledge they need to succeed in the twenty-first century.

Procedural Concern

As emphasized by Herschbach (2011), teachers encounter significant challenges when integrating hands-on activities with engaging cognitive processes during instruction. This challenge is compounded by the lack of consensus and clarity in instructional approaches, as well as inadequate training among teachers in integrated STEM education, leading to confusion and inconsistency (Breiner et al., 2012). Furthermore, many teachers feel ill-equipped to effectively utilize STEM activities in the classroom, underscoring the critical need for comprehensive training and support (Bybee, 2010; El Fadil et al., 2018).

According to Desimone (2009), improving teacher training and professional development programs is essential to address the challenges faced in STEM education. Offering comprehensive training that focuses on integrating hands-on activities, cognitive processes, and effective instructional strategies can equip teachers with the necessary skills and confidence to navigate the complexities of STEM education. It is important to move away from biases towards specific evaluation methods and instead focus on a balanced approach that incorporates observation, interviews, surveys, and other research-backed measures.

Motivational Concern

Motivation plays a crucial role in shaping students' engagement and achievements in STEM education. Various key factors, such as intrinsic motivation, extrinsic motivation, self-efficacy beliefs, goal orientation, perceived competence, task values, and social and cultural contexts, significantly influence learning outcomes (Eccles & Wigfield, 2002).

Briefly speaking, intrinsic motivation refers to the internal desire to engage in an activity for its own sake, driven by interest and enjoyment. In STEM education, this can be fostered through real-world problem-solving by incorporating the TDP or inquiry-based learning, enabling students to find joy in the learning processes themselves (National Research Council, 2012). Extrinsic motivation, on the other hand, involves engaging in an activity to achieve external rewards or meet teachers' requirements to avoid punishment. In the context of STEM, extrinsic motivators might include grades, competition, or recognition. While often seen as less ideal than intrinsic motivation, extrinsic motivation can still be utilized to encourage participation and effort (Deci & Ryan, 2000).

According to Wigfield and Eccles (2000), expectancy-value theory suggests that students' motivation is shaped by their expectations of success and the value they attribute to a task. In the context of STEM education, this implies that students are more motivated when they have confidence in their ability to succeed in STEM tasks, such as integrating knowledge from various school subjects and using technological tools. Additionally, they are motivated when they perceive the relevance and significance of STEM skills for their future careers.

By recognizing the multifaceted nature of motivation and its impact on student outcomes, educators can design instructional strategies and learning environments that cultivate and sustain motivation in STEM education. This includes providing opportunities for hands-on experiences (Hidi & Renninger, 2006), promoting a sense of competence and mastery (Bandura, 1997), and fostering collaborative and supportive learning environments (Johnson & Johnson, 2009). To enhance motivation in STEM education, educators can go beyond the boundaries of traditional teaching methods and incorporate innovative approaches. This can involve using project-based learning (Thomas, 2000), the Technology Design Process (El Fadil & Najar, 2023), integrating technology and digital tools (Kay, 2006), and embracing active learning strategies (Freeman et al., 2014). By highlighting the relevance of STEM subjects to real-world contexts, educators can help students see the practical application of their learning (Eccles & Wigfield, 2002).

Technological Modes Concern

Technological modes in education encompass a variety of tools and methods that leverage technology to enhance teaching and learning. These include virtual labs, simulations, online resources, and other digital tools. One significant advancement in science and engineering is the emergence of virtual labs, which offer unique opportunities to enhance practical learning experiences. These digital environments provide interactive and immersive experiences, fostering curiosity, critical thinking, and problem-solving skills among students (Johnson et al., 2014).

According to Johnson et al. (2014), virtual labs have proven effective in promoting engagement and a deep understanding of scientific concepts. They allow students to explore and experiment in a controlled and safe environment, enabling them to make connections between theory and practice. Additionally, virtual labs provide access to knowledge when the phenomenon being studied is inaccessible or uncertain using traditional methods, such as when it is too fast, too slow, too far, or infinitely small (Honey et al., 2014).

For example, students can use virtual labs to observe and manipulate objects at the atomic or molecular level, study fast motions such as oscillations, explore astronomical phenomena that occur over vast distances, or conduct experiments in extreme environments that are impractical or unsafe in a physical laboratory. By integrating both virtual and real-life modes of learning, educators can create a more comprehensive and dynamic learning environment. Virtual labs can simulate complex experiments and scenarios, providing students with interactive and immersive experiences that foster curiosity, critical thinking, and problem-solving skills (Johnson et al., 2014). On the other hand, real-life modes offer tactile and experiential learning opportunities, allowing students to engage with physical materials and environments.

In this paper, we define a STEM activity as a teaching and learning scenario in which students collaborate in small teams, integrating knowledge from diverse disciplines such as science, engineering, and mathematics. These activities involve the use of technological tools to tackle problems and engage in hands-on problem-solving experiences.

To address the challenges and inconsistencies in the implementation of STEM activities, the proposed project aims to introduce seventh-grade students to the concepts of variables and functions (*mathematics*). This will be achieved through an activity centred around pendulums (*science*). As well, the project will incorporate elements by challenging students to design and make their own pendulum (*engineering*). The use of virtual labs will be integrated to further enhance the learning experience (*technology*).

By combining these elements, students will have an opportunity to apply their knowledge of variables and functions in a real-world context. They will explore the principles of pendulums, investigate how different variables (independent and dependent) affect their behaviour. The use of virtual labs will allow students to simulate and observe the behaviour of pendulums under different conditions that are almost impossible in a traditional lab setting (very short, very long, very heavy, very light), providing a dynamic and interactive learning environment.

Research Questions: the proposed project aims to address the following research questions:

- To what degree do STEM activities, including the integration of virtual labs, contribute to students' comprehension of variables and functions?
- In what ways do STEM activities influence students' motivation to grasp abstract concepts and actively engage in investigative processes?

By exploring these research questions and considering the role of motivation in STEM education, we can gain valuable insights into the effectiveness of STEM activities, including the use of virtual labs, in enhancing students' understanding and motivation in both mathematics and the TE.

Conceptual Framework

This study encompasses various pedagogical approaches and underlying philosophical concepts influencing observed teaching practices. The framework examines pedagogy from a practical perspective, incorporating three modes of transfer: cognitive constructivism, social constructivism, and the technological mode.

Cognitive constructivism centres on individual learning, emphasizing internal rigor and knowledge construction through effective teaching strategies (Williams, 2016). According to this perspective, learners actively construct their understanding by integrating new information with their existing knowledge (Piaget, 1972). Moreover, Bruner's works have significantly influenced cognitive constructivism (Bruner, 1960), emphasizing learner-centred activities, problem-solving, and critical thinking to foster meaningful learning experiences.

Social constructivism stresses knowledge construction through social interactions, including engagements with teachers and peers. Vygotsky's sociocultural theory posits learning as a collaborative process occurring through social interactions and meaningful activities (Vygotsky, 1978). Through dialogue, scaffolding, and cooperative learning, learners actively construct knowledge, negotiate meaning, and develop cognitive and social skills (Johnson & Johnson, 1999).

Embed a focus on equity and inclusion within the project involves acknowledging diverse learners' needs, ensuring equitable access to educational resources and opportunities, and promoting inclusive teaching practices. Scholars such as Ladson-Billings have extensively written about the importance of equity and culturally responsive teaching (Ladson-Billings, 1995). By emphasizing equity and inclusion, the framework can guide educators in creating learning environments that accommodate the diverse strengths, interests, and backgrounds of all students, fostering a supportive and inclusive STEM education ecosystem.

The technological mode underscores teaching facilitated and supported by digital tools and methods. Technology has become integral to modern education, offering avenues to enrich teaching and learning experiences (Koehler & Mishra, 2009). The integration of technology can create interactive and engaging learning environments, enhance information access, and facilitate communication and collaboration (Liu & Reed, 1994). Digital tools and resources also support inquiry-based learning, problem-solving, and creativity (Means et al., 2010).

The integration of these pedagogical approaches forms a comprehensive framework for understanding teaching practices and their impact on student learning outcomes. By incorporating cognitive constructivism, social constructivism, and the technological mode, educators can design learning environments promoting knowledge construction, social interaction, and effective digital tool utilization. This holistic pedagogical approach aligns with contemporary educational theories and practices.

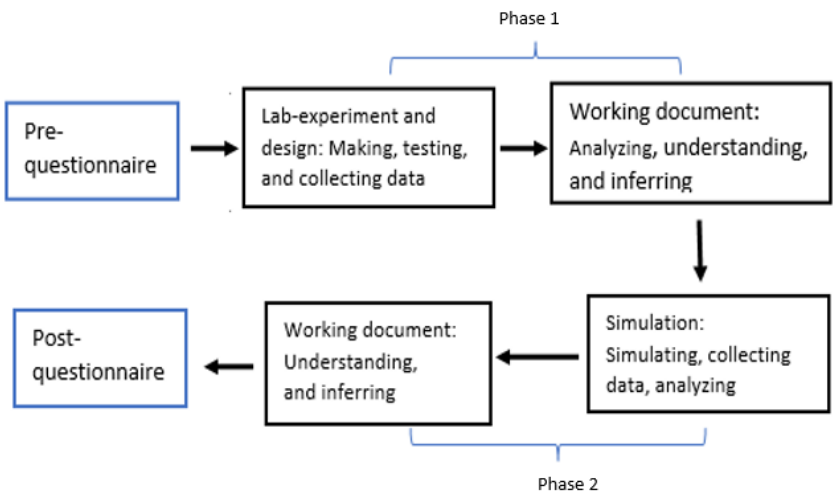

Figure 1. Project implementation phases (Source: El Fadil & Najar, 2022)

Method

In the Quebec Curriculum, where STEM is not explicitly included, we often promote transdisciplinary learning through Technology Education and its associated processes. In this study, we initiated our study with a physics activity centred on pendulums. This choice is justified by the natural connections between physics, engineering, and technology, as well as physics' ability to foster interdisciplinary dialogues and methodologies that transcend traditional disciplinary boundaries (Sinatra et al., 2015).

The project involved designing, making, and analysing a pendulum, using two teaching phases outlined in Figure 1.

The aim was to gain insight into the interrelationships among the variables of the pendulum. Data was collected from a seventh-grade classroom with 20 students. We understand that the number of participants in our study is insufficient to achieve representativeness or support in-depth statistical analysis. This limitation stems from the restricted access to schools due to COVID-19 pandemic.

To ensure the credibility of our findings, we followed a case study design and used multiple data sources (Yin, 2003). These sources included pre- and post-questionnaires, hands-on observation during the TDP, as well as a working document that captured students' understanding.

The first phase focused on designing, making and testing of a simple pendulum to explore its function and the variables involved. It began by assessing students' prior knowledge through a pre-questionnaire designed around three fundamental principles: (1) Mitcham's typology of technology, which encompasses objects, activities, knowledge, and volution (De Vries, 2021; Mitcham, 1994); (2) STEM epistemic practices, including investigating, sense-making, and critiquing (Bevan et al., 2019); and (3) content derived from the Mathematics, Science, and Technology subject area in the Quebec Education Program (Government of Quebec, 2006). Students then designed, made, and tested the pendulum using lab-tools to measure its variables. They worked in small teams and generated ideas for designing a simple pendulum, considering the key factors that influence its swings. During a group discussion, students identified mass, length, period, and deviation (angle) as important factors to consider in analysing the pendulum's behaviour. We then prompted them to think deeply about how to effectively operationalize the variables.

After a second round of discussion, they identified mass (m), length (l), angle (θ) as independent variables, while the period of oscillation is identified as the dependent variable, T=f(m,l, θ), which cannot be controlled.

To explore the relationship between these variables, students were assigned the task of investigating the impact of an independent variable (m, l or θ) on the period of the pendulum (T=$f(m)$, T=$f(l)$ or T=$f(\theta)$). Collaborating in teams, students engaged in designing, creating, and testing simple pendulums, utilizing a variety of technological and lab tools.

To gather data on the effect of length ($T = f(l)$), students designed pendulums with various lengths of wire (l = 30 cm; 40 cm; 50 cm; 60 cm; and 70 cm). For each length l, they conducted three measurements and calculated the average. Subsequently, they changed the wire (l) and repeated the measurement process. Figure 2 provides further details on the experimental setup.

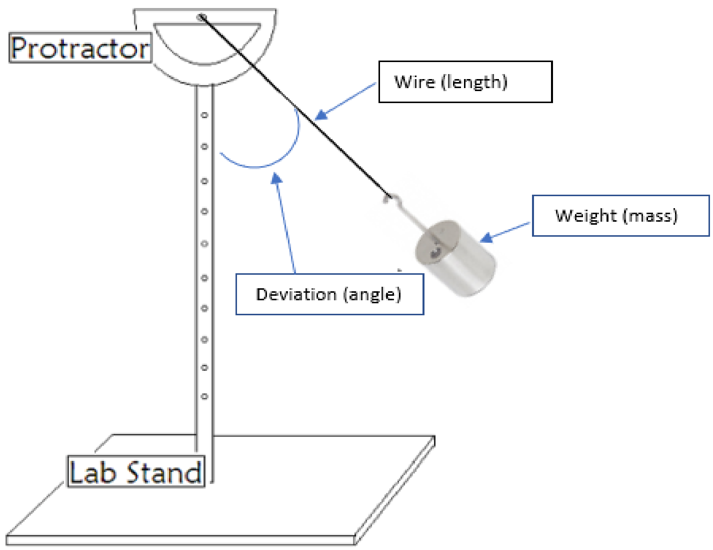

Figure 2. An Example of Designed Pendulum

To gather data on the impact of the mass as an independent variable, the group designed a pendulum with a fixed wire and varied the weights suspended to its free end. They used weights of mass *m = 20 g*, *50 g*, *100 g*, and *200 g*. Regarding the angle as a variable, students encountered issues with the stability of the setup, which resulted in the cancellation of its experimentation. After completing the design activities, the students answered questions related to graphical analysis and extrapolation.

In the second phase, students used a simulation tool (virtual lab) available on the platform phet.colorado.edu/ to simulate pendulum motions and gather data, replicating the physical experiments conducted in phase 1. The students were prompted to think critically about the accuracy of their results and the ability to draw valid inferences about the relationship between independent and dependent variables. To evaluate the impact of the design activities on the students' understanding of variables, functions, and the TDP, a post-questionnaire was administered.

Results and Discussion

The first category of questions in the pre- and post-questionnaires addresses pupils' prior knowledge about pendulums and how they work. Here is a sample of questions provided in the first category:

- Do you know what a pendulum is?
- Can you explain how a pendulum works?
- What type of energy do you think causes pendulums to move?

Data collected from the pre-questionnaire indicates that out of the 20 respondents, only one student did not know what a pendulum is. However, the remaining 19 students confirmed their familiarity with the concept of a pendulum, although many of them struggled to identify its components. Also, only 6 out of 20 respondents were able to accurately identify the parts of a simple pendulum and correctly associate its function with the swinging motion.

Regarding the variables and the type of energy involved in a pendulum motion, only one out of 20 students showed a limited recognition that the mass of the suspended weight and the length of the wire are variables. Similarly, only one student made a connection between energy and the gravitational force.

The second category of questions focuses on scientific and mathematical concepts that are essential to understanding the physics of pendulums. Here are some questions from the second category:

- Explain in your own words what the term "variable quantity" means.
- What method or technique can you use to describe or represent a situation involving two variable quantities?
- Can you determine which variable is considered the independent variable and which one is the dependent variable in a situation where two variables are involved?

In contrast to the first category, the second category of questions display varying levels of understanding. Regarding the meaning of "variable quantity," eight students mentioned that it refers to a quantity that can change. One student stated that it signifies an unknown quantity, another mentioned that it is an expression used in algebra, while the remaining students had no idea about its meaning.

With reference to the method that can be used to represent a situation involving two variables, two students mentioned charts and graphs, while another student mentioned algebraic equations.

Regarding the ability to distinguish between variables, only 3 students claimed that they can correctly identify which variable is independent and which one is dependent.

Table 1. Length-Period Collected Data

L: Pendulum length (cm)	30	40	50	60	70
T: Period (s)	1,1	1,3	1,4	1,6	1,7

The working document provided to the students contains a series of questions that specifically relate to both the process of collecting data from a designed experiment, and how to effectively organize this data into table of values and graphs to make a successful analysis. After designing and making their pendulums, students collected data on length-period variables (T=$f(l)$), (Table 1 and Figure 1). Therefore, they plotted correspondent graphs.

To gain insight into the students' analytical abilities, we instructed them to use their tables and graphs as references to examine the relationship between the two variables (Length & Period). This task aims to assess not only their proficiency in interpreting and analysing data based on the visual representations created, but also their ability to think outside the box, by using extrapolation and inference.

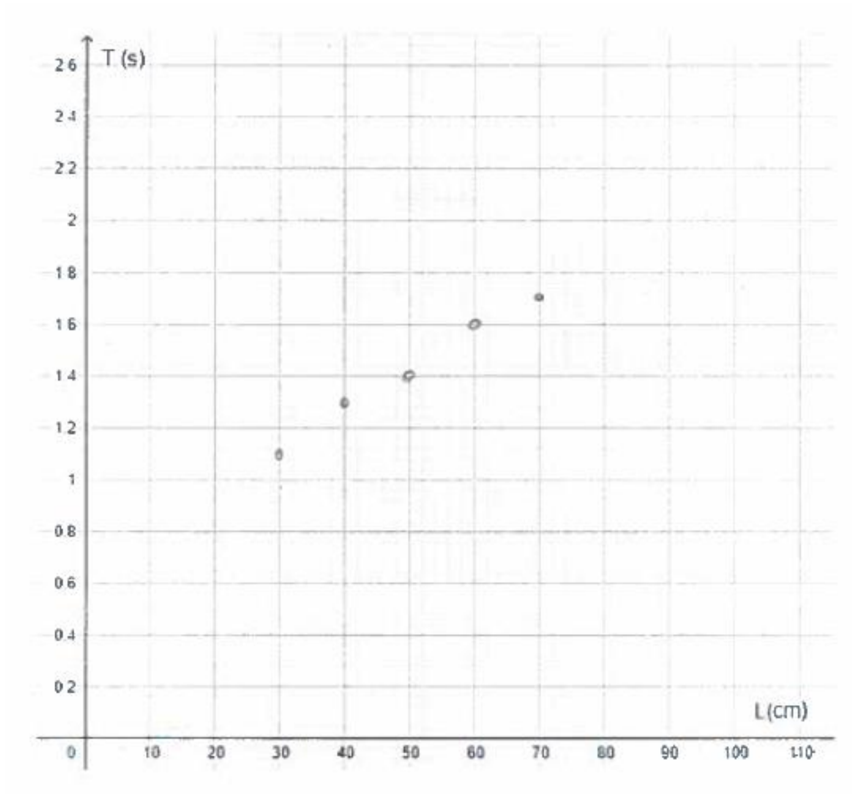

Figure 3. Length-Period Graph

The pre-questionnaire's responses indicate that 14 out of 20 students demonstrated the ability to extrapolate their graphs to predict periods for some hypothetical pendulums. For instance, we asked them to determine the periods of the 20-cm-pendulum, 55-cm-pendulum, and 90-cm-pendulum. After analysis, it became evident that the 14 students were able to formulate acceptable answers, as depicted in excerpt 2 (Figure 2).

Table 2. Period Extrapolation Question and Student Responses

Question: can you determine, from the graph 1, the oscillation period T of	
	Students' answers
a 20-cm pendulum?	T= 1 second
a 55-cm pendulum?	T = 1,5 second
a 90-cm pendulum?	T = 1,9 second

To investigate the relationship between mass and period ($T=f(m)$), students conducted a second experiment. They made another simple pendulum with a fixed length and suspended successively various weights at its free end. The responses indicate a similar level of understanding among the students as in the previous experiment, with the exception that the period varies only slightly as a function of the mass.

The incorporation of digital tools as virtual laboratories has proven to be beneficial for students in enhancing their comprehension of abstract concepts.

In the second phase, students replicated the same experiments conducted in phase 1, but in a virtual environment. This activity provided students with an opportunity to reflect on the advantages and limitations of physical laboratory experiments, simulations, as well as modelling. Through this second phase, students learned how the virtual environment empowers them to surpass the limitations imposed by the physical constraints of the lab-equipment. It allowed them to explore and push the boundaries of their knowledge in ways that may not have been possible in the traditional lab setting. The responses indicate that 14 out of 20 students successfully collected data from the simulation platform, generated graphs, extrapolated data, and provided answers to related questions.

After completing the second phase, we proceeded to assess their understanding by administering a post-questionnaire. The analysis of the data collected from the questionnaire revealed that all students had acquired a solid comprehension of the steps involved in the TDP and demonstrated a clear understanding of both the concept of a simple pendulum and how it operates. Additionally, it was observed that 16 respondents displayed an understanding of the connection between the function of a pendulum and the period of its swings, which is primarily influenced by the length of the wire.

However, the analysis of both the post-questionnaire and the working document indicates that only two out of the 20 students were able to make a correlation between the force of gravity and the potential energy involved in the oscillating motion of the pendulum. To gain a deeper understanding of the impact of this project on mathematics learning, we included a question about the inverse function in the working document. We asked the students how they could design a pendulum to achieve a specific period of oscillation. For instance, we inquired whether they could calculate the length (l) of pendulums that oscillate respectively with periods of T = 1.00 s, 1.40 s, and 2.00 s.

The responses show that 11 out of 20 students have used their graphs by starting their lines from the y-axis, which corresponds to the period (T), to find the lengths (l), on the x-axis, of the three hypothetical pendulums, as shown in excerpt 3 (Table 3).

Table 3. Inverse function questions and students' answers

Question: can you determine, by using graph 1, the length l of pendulums that have the following period of oscillation?	
	Students' answers
a 1,0-second pendulum?	l = 20 cm
a 1,4-second pendulum?	l = 50 cm
a 2,0-second pendulum?	l = 70 cm

Conclusion and recommendations

This study provides valuable insights into students' prior knowledge of pendulums and their comprehension of the scientific and mathematical concepts related to pendulum motion. While many students were familiar with the concept of a pendulum, they faced challenges in identifying its components and understanding the variables and energy involved in its motion.

Data collected from both traditional laboratory settings and virtual environments showcased students' ability to gather and analyze data, create graphs, and make extrapolations using visual representations. The hands-on, inquiry-based learning approach employed in this study slightly improved students' understanding of abstract concepts like variables and functions.

Collaboration among students during the project had a positive impact on peer learning and social constructivism, particularly when negotiating pendulum variables. Students engaged in exchanging ideas, discussing observations, and working together to solve problems using various approaches, including traditional labs, virtual labs, and working documents. This collaborative learning environment fostered the development of communication skills, teamwork abilities, and the capacity to consider multiple perspectives, reflecting the social nature of knowledge construction.

However, it is important to acknowledge the limitations of this study. The sample size was relatively small, with only 20 students participating amidst COVID-19 restrictions, which may limit the generalizability of the findings. In addition, the study focused exclusively on pendulum motion and variables, without exploring other areas of science and engineering. To provide a more comprehensive understanding of the topic, further research is needed, building upon the findings of this study. Such research endeavors will enable educators and researchers to enhance teaching strategies and promote meaningful learning experiences for students in STEM education.

Future studies should aim to encompass larger sample sizes and a broader range of topics to gain a comprehensive understanding of the impact of STEM learning experiences on students' understanding of variables and functions. Implementing longitudinal designs could assess the long-term effects of such learning experiences. Furthermore, incorporating qualitative methods like interviews or observations may provide deeper insights into students' thought processes and learning experiences. Exploring the effectiveness of different instructional strategies and interventions could contribute to the development of more effective pedagogical approaches in teaching variables and functions.

In order to foster inclusivity, diversity, and a comprehensive understanding of STEM concepts across diverse cultural backgrounds, we believe that it is so important to incorporate cultural considerations into the investigation. This can be achieved by integrating Indigenous perspectives, traditional practices, and community-based approaches into the design and implementation of problem-solving activities.

Ultimately, assessment strategies are the cornerstone of teaching and learning. Educators and researchers must develop appropriate assessment strategies that align with the goals and objectives of STEM activities, covering knowledge, processes, skills, collaboration, and the use of digital tools. Performance-based assessments, rubrics, and self-reflection exercises can be valuable tools to evaluate students' understanding, problem-solving abilities, and collaboration skills. By implementing these strategies, educators can gauge the effectiveness of their teaching methods and provide students with meaningful feedback to enhance their learning experience in STEM education.

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29.2

Student's perception about mechanical stress and what is most important for learning during a practical task using digital interactive lab description

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Abstract
This study investigated student's knowledge and understanding of mechanical stress including strain, and the relation between mechanical stress and strain, using material created by the authors of this text. It also investigated what the students perceived helpful for learning. The material was a complete laboratory setup and was intended to be simple and visual, including a digital part. During the studies in a Swedish upper secondary school, students enrolled in the technology programme took a general introductory course in solid mechanics. The students' participation in our study was composed of four classes. The study was implemented by answering a questionnaire prior to laboratory and a similar one after the laboratory, 85 out of 107 students answered both questionnaires. A thematic analysis was applied on the material, resulting in six thematic groups based on the students' previous knowledge and how much they have learned from the laboratory. To find correlations between the thematic groups, classes, and what the students perceived important for learning, a One-way Analysis of Variance (ANOVA) with multiple comparison post hoc test was performed. A significant difference between the class and the thematic groups was found ($p<0.05$). Another significant difference was found between the teacher and the class the students were in ($p<0.001$). This study showed that the teacher was important for the students' perception of solid mechanics during this laboratory and that the interactive lab description played less roll. The teacher's importance depended on what class the students were in.

Keywords
Technology, solid mechanics, practical task, interactive links, learning, teacher

Introduction
A didactical model may be used to explain and reason about the different teaching approaches that a teacher may conduct. The teaching approach depends on the context that is to be taught (Wickman et al., 2018). This is also discussed by Hattie (2003). The didactical model should not only be used when planning and conducting a single learning activity, but also in its evaluation (Jank & Meyer, 2003). The didactical model used in the laboratory was to keep equipment simple to use and visual in nature. (Hattaja et al., 2019). Follow the development of Quality 5.0 and their excellence model (SIQ, 2022) the success of an organisation requires motivated teachers and the relation between the student and teacher is important.

Technical solutions are often a compromise of many properties; as an example between choice of manufacturing method, chosen material, weight and solid mechanics calculations. Teaching technology in upper secondary school in Sweden is an activity of great complexity and the important role the teacher has for student learning is well established. The interest for the importance of the teacher during student learning has also been interest over a long time (eg. Darling-Hammond, 1996). The teacher´s role may concern, for example, relational aspects where a good teacher-student relationship is fundamental for student´s learning. Students describe, when describing a good teacher, a teacher that shares the responsibility of learning together with them and that the teacher know them not only as a learner. The teacher's knowledge of the taught subject is described as less important than both passion for teaching or the subject itself. A good teacher cares about the students' self-esteem and their confidence (Hirsch, 2021). Furthermore, the teacher's attitude towards the subject is also of importance as previous studies have shown that teachers are usually reluctant to teach subjects, they have little or no confidence in (Holroyd and Harlen, 1996). This of course will have an impact on teaching of the students, especially in a course with a broad course plan. For junior students, textbooks and class notes are important for learning, but in higher grades digital interactive learning becomes more important for supporting the learning process. Digital interactive learning is, for example, interaction between the teacher and student through chat groups (Hirsh and Sergolsson, 2021).

Experimental work plays an important role in learning science due to the visual effect of the experiment. It helps to first learn the method of the scientific experiment before performing a practical task on the subject. Secondly it helps the students understanding of the connections between known concepts and gaining learnings of known scientific knowledge. Experiments are often seen as a tool for students to learn new concepts and should be seen as a means of communication and less as a discovery (Millar, 2004) The interactions between teacher and students are very important for learning during an experimental task. This includes how the teacher acts and what is communicated (Hogstrom, 2010). The visual attention from teacher has a direct impact on the students learning (Haataja et al., 2019). During the technical design process the students usually create a model by a practical work through experimentation in a lab with lab equipment or simulate a computer model. The technology course is mandatory in Sweden and is studied in all ten years of compulsory school. It has a broad curriculum where students are introduced to both the engineering aspect as well as to the importance of technology in daily life. The course also highlights, among other things, different historical technical advancements as well as the importance of stable constructions (Skolverket, 2019a). In Table 1 it can be seen what the students learn about construction over the school years.

Table 1. Number of students in each thematic group.

School year	Technology education
Compulsory school 1-3 and pre-school class	Start with materials and construction (Skolverket, 2019a).
Compulsory school year 4-6	Start with stable construction and continue with reinforcements and trusses (Skolverket, 2019a).
Compulsory school 7-9	In the last three years they talk about tensile and compression strength, elasticity and hardness. In year 9 the grade criteria for the students includes that they should be able to: carry out technical development and construction work (Skolverket, 2019a).
Upper secondary school	In the final year of the compulsory school, students apply for an upper secondary school programme and about 8.4% of all students choose a program with a technology specialisation (Skolverket, 2023b)
University	Engineering education or similar

In the programs in upper secondary school all students are introduced to the subject of technology through a compulsory introductory course. This course has many perspectives including ethical aspects on technology, technical properties of materials including calculations, and the technical design process. (Skolverket, 2022).

The technical programme includes graduation goals, covering obligatory and optional courses (Skolverket, 2023a). Each course has a course plan with central content and criteria that the students must achieve. Solid mechanics calculation and designing are prominent in the technology course plan. In the introductory course at the technical programme, and even though its role may have lessened, it is still widely used when teaching solid mechanics calculations. Materials is one other important aspect and still play a significant role in the technology course criteria.

Technical calculations are also included in the course criteria (Skolverket, 2022) in the new course plan valid from June 2025. Designing is specifically mentioned as; concepts of designing, theories for designing, and models for designing. Calculations related to designing are mentioned in the central criteria for the course plan (Skolverket, 2024). Simulations have also been used to help students in their learning and was shown to be helpful in learning theoretical concepts in a more accessible manner (Carbonell, 2016).

Many studies have investigated how digital aids can help students perform practical tasks (Barrow & Rouse, 2009; Karlsudd, 2014; Usulu & Usulu, 2021). An international study (Inquimbert, 2019) reported that well adapted digital tools decrease the stress level students feel during practical tasks. Blended learning, a hybrid between digital and on place experiments, can be implemented to increase collaboration between laboratories, reduce costs, and to share knowledge and experiences (Nau, 2022). Previous studies (Saleh, 2009) have shown that visual aids during or before lab time can help the students to properly prepare for the lab. Visual aids also help the teacher to explain and work as a supplement for the practical work. (Skolverket, 2021) express importance of digital tools that can be implemented to ease learning by students. Digital tools increase motivation and engagement of students if it supports collaboration. Studies from (Skolverket, 2022) show digital aids bring value to learning if they are instructive and to support communication between students and between student and teacher.

This study focuses on the students initial learning of stress calculations via one lab experiment. Thus, an interactive digital material was designed specifically for a lab experiment involving visual effect of mechanical strain and stress calculations based on measured results. The students performed the practical experiment by measuring elongation of a rubber band using different weights and calculated stress and strain. During the practical task students used an interactive material which described the lab with an interactive formula sheet. Additionally, earlier research (Forsell, 2019a) showed that the attitude the teachers have when approaching solid mechanics and construction as a learning activity was important for the students learning. In the study some challenges regarding teaching solid mechanics were identified. The present study focuses on one of these challenges, namely the learning of new terms and concepts like mechanical stress and strain. The study was designed to evaluate the impact of digital support on students learning also considering the role of the teacher. The interactive material was used during the lab experiment. The students are asked about their knowledge and asked to rate the importance of different factors for learning.

Aim

The aim of this study was to evaluate student learning while using and following a digital lab description designed by the authors. The study was designed with the intention to view the digital support the student received through the lab description in the learning of mechanical stress and strain. The material included a practical task and the students had, among other things, a description with digital links and a formula book, also with digital links. Further the aim was to identify, while performing the task, what the student thought was most important for their learning of mechanical stress and strain. More specifically we will address the following research questions:

- What did the students know about mechanical stress before the experiment and how did their knowledge change after?
- What in the material do students perceive as helpful for their learning about mechanical stress?
- Is there any difference in what the students perceive helpful depending on their knowledge before and after or what class they belonged to?.

Method

Participants

The participants consisted of 107 students in total, recruited from four different classes of one school. The school chosen school was a big school close to Sweden's biggest city. The average merit value for the technical programme in Sweden was 260.5 (Skolverket, 2023c) and the median at the school was 289 and the lowest 255 (Nacka,2023). This means this school had students with slightly higher grade than average. All classes were part of the technical program after upper secondary school selection. The selected classes criteria had high degree of interest in learning technology as subject. The students were at the second year of three years of upper secondary education. Students read the last term of the technical basic course. The students went to four different classes and all classes had different teachers. None of the participants had any previous knowledge of solid mechanics in their course before. Although, as told before, all the students should have read about stable construction and materials in compulsory school. All students were informed about the study and its purpose, including that it was voluntary to participate. The students filled in a form where they accepted participation. The students received a form to answer before and after the practical task and 85 students answered both forms. All the questions on the forms were answered. The ethical advice and rules for the Swedish research council where followed (Vetenskapsrådet, 2017).

Experiment

An interactive lab description of a tensile test was designed and implemented. The test was performed in three different ways. The lab description and formula sheet, both had interactive links to aid the students to understand words and new concepts. The links had explanations, pictures and/or videos that explained the terminology. See example in figure 1.

Uppgiften

Uppgiften som handlar om hållfasthetslära går ut på att rita en dragprovkurva som visar relationen mellan spänning och töjning, detta är grundläggande inom hållfastheitsläran, samt kunna tolka resultatet (ku på en dragprovkurva. lag (wikipedia) sträckgräns (wikipedia), brottgräns (w asticitet samt säkerhetsfaktor.
Ett exempel på dragprovkurva.

1. Starta med att rita upp din figur hur du skall sätta upp din provutrustning så att du mäter det som skall mätas. Vad är det som du skall mäta?
2. Börja med att dra med händerna i gummibandet och beskriv vad du ser. Du skall skriva ned vad du tror, vilka materialegenskaper som skall vara uppfyllda för gummibandet som du kommer att göra prov på.
3. Sätt samman din mätutrustning och gör minst fem olika mätningar med olika vikter där du för varje vikt mäter gummibandets förlängning.
4. Genomför ett antal beräkningar med hjälp av dina mätningar och rita graf där du beskriver relationen mellan spänning och töjning. Grafen du ritat är en spänning-töjningskurva. Du behöver veta vad mekanisk spänning och töjning är, det går även att titta i formelsamlingen.

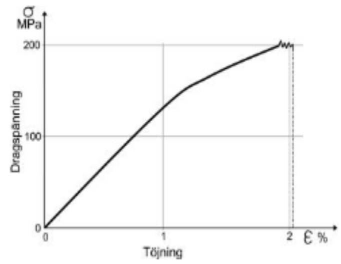

Fig 1. Exempel på spänning töjningskurva

Figure 1. Example of explanation from interactive lab description.

Before and after the interactive lab task the students received two questionnaires with identical questions about solid mechanics to answer. The questions to the students shortly described the terms so the students could recall them from earlier studies in grade school. The questions were asked in Swedish but are here translated. The questions posed were the following:

- Mechanical stress occurs in a material when you try to pull out the material so that it becomes longer. Mechanical stress is defined as a force acting on a surface that is orthogonal to the force. What do you know about mechanical stress?
- Strain occurs when pulling a material. Strain is how much you extend a material relative its original length. There is a relation between strain and elongation. What do you know about this relation?
- Stress and strain relate to each other. When you draw a graph (curve, as a mathematical function with appearance f(x)= x) that describes the relationship between mechanical stress and elongation, you get a certain appearance that is unique for the material being studied. What do you know about the graph? What does it describe?

The questions were open and were to be answered with free text. In the questionnaire, after the experiment, the students were also asked to rate the importance of different learning aids, previous knowledge, or digital links for their own learning. The rating covered; their own preparation (how they prepared for before the laboratory experiment), the lab description, the interactive links, the interactive formula book, the course book (all the classes had the same course book), the teacher, and the execution of the lab (the performance of the experiment itself). The students were asked to rate everything on a six graded scale, where six was considered the most important thing and one the least important one. Each of the learning aids were rated independently, hence everything could be rated the same importance.

Thematic analysis

As an initial step, a thematic analysis (Braun and Clark e, 2006) was applied where six different groups (here after called thematic groups) were identified. Each group within the thematic groups was defined based upon the student's answers from the questionnaires, combining answers both before and after. Depending on how the students expressed their understanding of the term mechanical stress including understanding of strain and the relation between stress and strain. All answers were analyzed, and comparison made between, before and after, the experiment. The answers to the three questions (see above) in the questionnaires were analyzed together. Since the questions were constructed to build on each other. If the student knew something about strain and not stress it was seen as the student knew some about strain or stress. All answers from students were put in the identified thematic groups. The number of students in each thematic group is shown in table 2.

The thematic analysis was performed as follows. First, authors became familiarized with the data. Followed by identifying significant statements, phrases, and sentences commonly used in the different answers. Themes in responses were identified where statements from students answers similar meaning were grouped to form themes.

Patterns in the answers were scrutinized and certain phrases found, helping in producing themes. Six thematic groups were created, which were then summarized and described The creation of each thematic group was done by looking at the student answers before and after the experiment. The 87 that answered, out of 107 students were put into these six groups that was determined through the thematic analysis. Each group had different perceptions of mechanical stress before and/or after the performed experiment. We did not order the themes in any order since we wanted to be open of the different result and perceptions of mechanical stress before and after the experiment. The thematic groups that were found during the thematical analyses was later used for a statistical analysis.

Table 2. Number of students in each thematic group

Groups	Number of students
Group 1	40
Group 2	7
Group 3	10
Group 4	2
Group 5	14
Group 6	12

Statistical analysis

A One-way ANOVA with multiple comparison post hoc test was used for the statistical analysis. The groups that came out with the thematic analysis were analysed against the rating the student provided on learning aids. In this analysis we assume the observations are normal distributed and the variances of the thematic groups are the same. The observations are independent of each other. This kind of analysis identifies different mean values between different groups that are analyzed. The (Ostertagova et al., 2013) analysis was used to find associations and relations between the different thematic groups generated in the thematic analysis regarding their perception of mechanical stress. It was also used to identified differences in the four different classes. More specifically the mean and standard deviation for the students' ratings were calculated. The statistically significant relations between classes and the thematic groups were also investigated. All the students went to four different classes in one school. The classes were investigated against the thematic groups generated from the thematic analysis. The classes were also investigated against the rating of learning aids that the students made before and after the practical experiment.

Result

In table 3 the results from the thematic analysis are described; student answers are used for exemplifying the thematic groups descriptions. In three of the four classes, most students were found in thematic group 1. Most of the students (thematic group one) learned less than desired even though the provided material, more specifically the digital links, was reported to have been of some help; the digital links were not the most important thing compared to teacher, lab description, formula book and the execution itself. It seems like the "normal way" of describing the lab was more important than the digital links. Table 3 shows different examples of answers from the different thematic groups. In figure 2 it can be seen the progress for each group where it can be seen that group 1 and 3 increased their knowledge most of all thematic groups.

Table 3. Groups of students with different perception of mechanical stress.

Thematic group	Example of an answer before the task	Example of an answer after the performed task
Group 1 Before the task: Students know nothing, or very little, about mechanical stress, strain, or about the relationship between the two. They expressed this by writing things that were wrong or by not writing anything at all. After the task: Students express some understanding of the concept mechanical stress but no or very little understanding of what how affects material or the relationship to strain. They could also have expressed some understanding of the relationship but nothing about the concept of strain.	"No idea, no clue, do not know". "Hardly anything. This relationship can be described with a formula: Graph shows when our material is stretched too much and can break"	"It's the power divided by the area in mm^2." "Nothing, doesn't understand what I should have realized with the graph"
Group 2 Before: Same as group 1 After: Express some understanding of mechanical stress, strain and the relationship between them.	"Nothing, nothing special"	"It depends on epsilon and the stress." "It is the mechanical stress. Elasticity".
Group 3 Before: Express some understanding of the concept mechanical stress. After: Express some understanding of strain and the relationship between strain and mechanical stress. The student also expresses an understanding of the concept mechanical stress.	"Looked a little at it. I know F/A = some stress. Beyond that I do not know more." "I know there is a relation between them. I do not know how you use it or what equation I should use." "I know that the graph probably gets a bigger y value the more stress you have and enough stress result in that the material will break." "It depends a lot on different material."	"I know now that F/A = stress. Thus, when you pull a material, the stress will increase depending on how big area you have." "I know now that strain is depending on the elongation and the original length of the material you had." "I know that the graph descries the correlation between stress and strain."
Group 4 Before: Express an understanding of the concepts	"A force on object that you pull." "A Rubber band." "But I do not know more	"An object is stretched when a certain stress occurs on the object. The more stress, the

mechanical stress and strain and the relation between them. After: They do not express any difference in understanding before the task as compared to after the task.	about this." "Do not know anything but my guess is that there is a relation between the length of the material and the force you pull with. There is also a relationship with what material it is. Rubber can stretch more than stone." " Have absolutely no idea."	more strain." "It describes the relationship between the strain and stress."
<u>Group 5</u> Before: Express no understanding of the concepts stress and strain or the relation between them After: Express no understanding on the concepts stress and strain or the relationship between them.	"Nothing". "The stress increases when you stretch something. "High stress means that the object you are pulling stretches a lot." "Proportional increase in the graph."	"Mechanical stress in a material occurs when you try to pull out the material so that it becomes longer." "Stress is a force that is applied on a surface that is perpendicular to the force." "Proportional relation. It should be equally constant."
<u>Group 6</u> Before: Express some understanding of the concept mechanical stress After: No difference in understanding after the task than before.	"Mechanical stress in a material occurs when you pull a material, so it gets longer."	"You calculate stress by F/A = the force divided by the area."

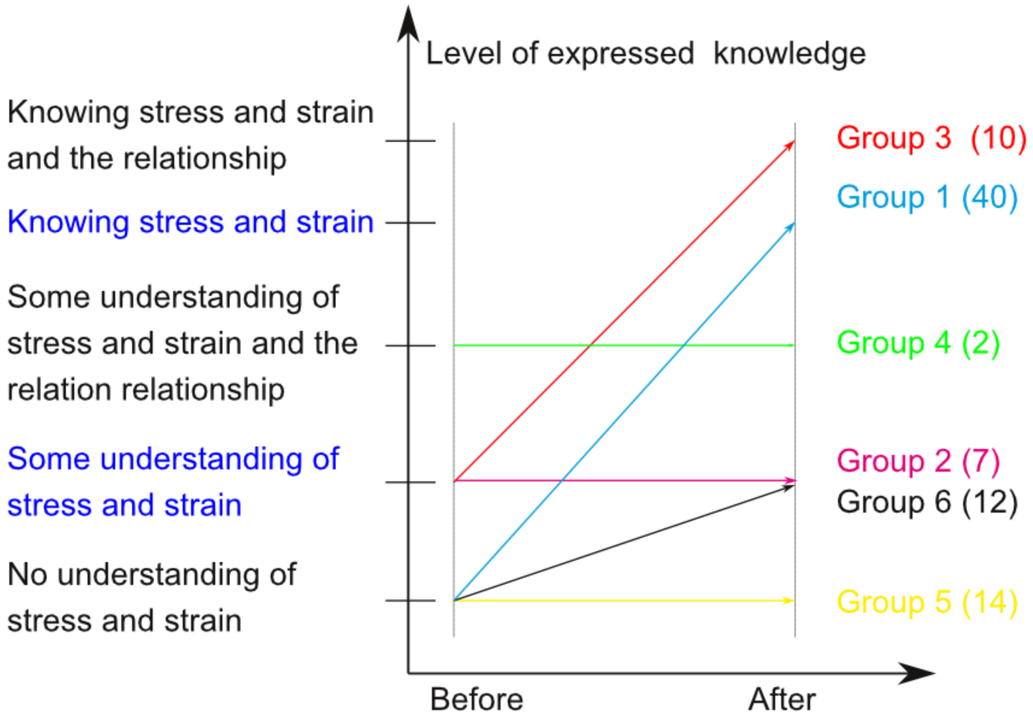

Figure 2. Groups of students with different knowledge on mechanical stress. Figure describes the understanding of mechanical stress before and after the practical task. The number in () are the number of students in the group.

The numbers in parenthesis are the number of students belonging to respective thematic group. Group 5 and 2 didn't change their understanding at all compared before and after the experiment. In table 4 it can clearly be seen how the students in different classes were divided in the different groups. The product of the class that went to a certain group can be seen in parenthesis, if there exist more than 10 students in the group. Most of the students went to group 1 and in class three more than 60% are placed in group 1. Execution of the lab was most important for the perception. However, there were significant differences between groups of students with different perceptions and different classes they belonged to ($p<0.05$). It seems that (table 4) shows that most of the students went to group 1 except in class 4.

Table 4. Number of students in the four classes divided in the different thematic groups. The % of the class that went to a certain group can be seen in brackets if more than 10 students in the group.

				Groups				Total
		1	2	3	4	5	6	
Classes	1	11 (39,3%)	4	5	0	6	2	28
	2	11 (61,1%)	2	2	0	2	1	18
	3	16 (64%)	1	0	0	3	5	25
	4	2	0	3	2	3	4	14
Total		40 (61,3%)	7	10 (11,8%)	2	14 (16,5%)	12 (14,1%)	85

Table 5 presents the results from the importance of different aids during the laboratory. If we look at table 6, the digital links are less important for group three than for the other groups. This difference was significant for group 1, 5 and 6. Group 3 is one of the groups that learned most but so did group 1 too. For the class versus what teacher there was also a significant difference ($p<0.01$). In class 2 the teacher seems less important and in class 1 most important of the four different classes (table 7c). In table 7b, it can be seen that the course book is more important in class 1 than in class 2 (a significant difference). This is the class that through the teacher was the least important of the classes. If we look at the digital links versus the classes (can be seen in table 7a), it can be seen a significant difference between class 3 and the other classes. Class three seems to think that the links are a little more important than the others (this difference was significant).

Table 5. The importance of different aids during the lab for the different thematic groups, expressed as mean values of a rating 1-6 where 6 was most important.

Groups	Own preparation	Description of lab	Interactive links	Formula book	Course book	The teacher	Execution of the lab
All the students	2.86	4.32	2.72	4.18	2.45	4.50	4.98
Mean Std	1.41	1.68	1.80	1.68	1.74	1.73	1.33

Table 6. The Groups they are in versus importance of group versus: a) own preparation b) description of the lab c) formula book d) course book, e) teacher f) execution of the lab g) interactive links. Rated 1-6 where 6 was the most important.

A)

OWN PREPARATION	Mean	Std.
1	2.78	1.510
2	3.43	1.618
3	2.90	1.370
4	4.00	2.828
5	3.00	1.961
6	2.42	1.311

B)

DESCRIPTION OF LAB	Mean	Std.
1	4.30	1.506
2	3.86	.900
3	4.30	.949
4	3.50	2.121
5	4.64	1.447
6	4.42	1.621

C)

FORMULA BOOK	Mean	Std.
1	4.28	1.853
2	4.14	1.345
3	3.50	1.841
4	3.50	.707
5	4.71	1.326
6	3.92	1.564

D)		
COURSE BOOK	Mean	Std.
1	2.15	1.657
2	2.57	2.370
3	2.40	1.647
4	2.00	.000
5	3.29	1.858
6	2.50	1.624
E)		
THE TEACHER	Mean	Std.
1	4.63	1.462
2	4.00	1.633
3	5.10	1.449
4	3.00	.000
5	4.86	1.834
6	4.50	1.732
F)		
EXECUTION OF THE LAB	Mean	Std.
1	5.30	.939
2	4.29	1.380
3	4.80	1.398
4	4.50	2.121
5	4.57	1.785
6	5.00	1.595
G)		
INTERACTIVE LINKS	Mean	Std.
1	2.70	1.728
2	2.57	2.370
3	1.40	.699
4	2.00	1.414
5	3.57	1.950
6	3.08	1.782

Table 7. The importance of a) class versus interactive links b) class versus book c) class versus teacher. Rated 1-6 where 6 was the most important.

a)

Class versus interactive links	**Mean**	**Std.**
1	2.50	1.95
2	2.22	1.31
3	3.52	2.00
4	2.36	1.22

b)

Class versus book	**Mean**	**Std.**
1	2.93	2.28
2	1.83	1.10
3	2.08	1.35
4	2.93	2.32

c)

Class versus teacher	Mean	Std.
1	5.71	0.54
2	3.17	1.30
3	4.24	1.69
4	4.93	1.39

Discussion and Conclusion

We could see from the result that approximately half of the students had some knowledge about mechanical stress prior to the laboratory (probably from compulsory school). Three of the groups raised their knowledge but three remained on the same level after the laboratory as before. The present study found a correlation between the importance of the teacher and which class the student belonged to when learning something new.; also, between the group and class. It is interesting that in all classes most students were put in group 1 according to the thematic analysis except class 4. One explanation could be that the answering rate was low in that class.

If we look at the student´s own preparation, group four had the highest value. Maybe the preparation led to their higher understanding before the task. The course book has low values for all the groups and maybe not so important for the students for this specific experiment. If we look at the importance of the teacher, the result imply that the teacher was very important for the outcome of the laboratory and depending on which specific teacher the student had, the teacher was more or less important. Could it be that a committed teacher gets students who prepare to a greater extent and then use the experimental material to a greater extent, but that they still see that the teacher is the "catalyst" to make it happen? The group with the highest importance was a group that changed understanding significantly and the one with the lowest stayed on the value they were at before the laboratory. One limitation is the difference in students that choose to join the study. So, the variation could have played in. The importance of the teacher has been of interest for a long time (Darling-Hammond, 1996). Teacher role is a complex task and the relationships with the students. That the course book was not most important in class 2 when the teacher was less important. For class 1 though the course book was more significant and important than in class 2. Earlier studies have seen course books and notes as important for learning (Hirsh and Sergolsson, 2021). We could not see that the course book was so important for the outcome of this learning experiment. Maybe if we asked for a longer period the course book would have been more important for learning. This was an isolated learning experiment and maybe that’s one reason for the other things rated higher.

Preparation, according to earlier research, is important for learning (Saleh, 2009). We did not have a digital preparation for the students. Maybe that is why the students rated their own preparation as low. A digital preparation might have helped the learning and change the importance of the students rating of their own preparation. It might also change the importance of the digital concept for the students. During a practical task time is limited and preparation might give the students more time to look at digital links etc… If the preparation were digital, it may perhaps help the learning; this would be interesting to further investigate in later studies.

Earlier studies have also seen that it could be the teacher's communication including facilitating support and instructions during the lab practical task, is important for the learning (Hogstrom, 2010). Since we only could observe what happen during one lesson the teacher's importance might of course be influenced of earlier lessons with the students. This since the students knew the teacher and the class.

We found that the digital links was most important for class three. Most of class 3 went into group 1 which had an increase in understanding.

The students in the school had high grades in comparison to Sweden in average and that of course influences the student knowledge before the experiment. Our belief is that some of the schools will have even lower starting knowledge than this school. We think that maybe the three groups that have no or little knowledge before the laboratory are more representative of average Swedish students. 107 students were asked to answer the questions where only 87 answered all questions.

The biggest drop in participants came from the ones that made the choice to only answer the first survey. For the students that felt they did not learn anything we do not know, so this is a limitation in our study. Since students were asked to answer the questions twice, they may choose to answer similar as first time and did not think further. One limitation is also that teachers different way of teaching influenced the result of the study. The teachers also help students in the classroom and there by intervene with the result of the practical task. Maybe less help from teachers would have made the digital links been used more.

Thus, we think the importance of the teachers dominated in our study and other significant differences might not have been not seen. Maybe with less help from the teachers we could have investigated how much help the digital aids gave to understand the concepts stress and strain. It might also be that the teachers facilitated the use of the digital aids and the students rated this as teachers' importance (Collison and Cook, 2013). The importance of using the digital links and exactly how it is used thus needs to be further investigated.

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Teaching programming in Technology teacher education: Revealing student teachers' perceptions

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Abstract

This study explores the changing landscape of technology teacher education, in relation to the increasing integration of digital content, especially programming, in teacher education for grades 4–6 (pupils 10-12 years old) and how student teachers in Sweden perceive this content. Limited research exists on student teachers in technology, particularly focusing on programming. This study therefore investigates student teachers' perceptions of teaching programming in technology education, after completing their technology course in teacher education. We answer the following research questions: What are the student teachers' perceptions of teaching programming in technology education? and How is potential subject didactics knowledge for teaching programming manifested in student teachers' perceptions of technology teaching? Using a phenomenographic approach, 25 student teachers' perceptions of programming in technology education were investigated through semi-structured individual and group interviews. Different perceptions were revealed and presented in four categories: (1) following instructions in a logical order, (2) learning a programming language, (3) solving technological problems, and (4) understanding and describing a technological environment. The results show that student teachers' perceptions of the subject of technology predominantly focuses on following instructions and the learning of a programming language. The identified potential subject didactics knowledge is constituted of an awareness of three critical aspects: understanding programming language, understanding programming as a way of solving problems, and the relationships of technological problems to everyday life and society. This study offers valuable insight into the development of competencies required to teach programming in technology, informing educational strategies and future research in this emerging field.

Keywords

Student teachers, Technology education, Programming, Phenomenography

Introduction

Over the last two decades, our everyday lives have changed and become increasingly digitalised; for example, in the form of robot lawn mowers, vacuum cleaners, and AI-supported banking transactions. The increasing digitalisation of society has contributed to changes in school curriculum documents in Sweden (Skolverket, 2017) and other countries. In Sweden, for example, digital technology and programming have been included as educational content in the technology syllabus since 2018. However, many teachers approach this new educational content with uncertainty (Sentance & Csizmadia, 2017; Vinnervik, 2023; Webb et al., 2017), because programming was not part of their own teacher education and the curriculum does not say how programming should be taught or how any difficulties learners encounter should be addressed (Passey, 2017). Therefore, there is a need for more knowledge about what is involved in teaching programming as part of teacher education and what competencies technology student teachers need to develop to be prepared for their future teaching career.

In line with this, there is a need to understand the perceptions of student teachers in order to inform teacher education (Koster et al., 2005; Schneider et al., 2013). In a study by Perez and Svensson (2024), the experiences of student teachers with programmed technological artefacts, including elevators, tumble dryers, traffic lights, and keyboards, were investigated. The result shows that student teachers' initial understanding of those programmed technological artefacts can be described as ranging from experiencing only the physical interface to components as and within a system, but these were still only a limited set of all the possible aspects of programmed technological artefacts (Perez & Svensson, 2024). In addition, student teachers' inadequate subject knowledge is a problem reported more frequently by primary school teachers than by their secondary counterparts (Selby & Woollard, 2014). This imbalance may be accounted for by the fact that primary school teachers are responsible for teaching a range of subjects, whereas secondary school teachers concentrate on fewer areas with more comprehensive training.

An important mission for primary teacher education should therefore be to instil student teachers with the ability to plan, implement, and evaluate the content of different subjects and understand the characteristics of each subject. In technology education, there is still a lack of research, specifically on student teachers' knowledge of programming. Therefore, it is imperative to investigate how student teachers perceive their upcoming teaching regarding programming in the subject of technology, after completing the technology teacher education course included in their training.

Aim and research questions

This study investigates student teachers' perceptions of teaching programming in technology education, after completing their technology course in teacher education. The following research questions are posed:

- What are the student teachers' perceptions of teaching programming in technology education?
- How is potential subject didactics knowledge for teaching programming manifested in student teachers' perceptions of technology teaching?

Programming as part of technology education and subject didactics

The study of teaching and learning of a subject content is often referred to as subject didactics, which can be seen as a bridge between subject knowledge and pedagogy (see for example Sjøberg (2001)). Subject didactics in, for example, the Nordic, German and French context thus refers to the subject-specific aspects of teaching and learning (Osbeck et al., 2018; Rothgangel & Vollmer, 2020; Schoenfeld, 1998). It addresses the three key questions: What (the relevant content), Why (the goals), and How (the appropriate methods) of teaching and learning within a certain subject (Rothgangel & Vollmer, 2020). Teacher education develops student teachers' knowledge in subject didactics (Osbeck et al., 2018; Vollmer, 2022). In technology education for grades 4-6 (pupils 10-12 years old) this involves both subject knowledge and its subject didactics. For instance, the 2018 revision to the Swedish compulsory school curriculum aims to help pupils understand the impact of digitalisation on individuals and society. Programming is included in several subjects, primarily mathematics and technology. The revised technology curriculum further states that pupils should acquire skills to control their constructions or other objects through programming, and reflect on opportunities, risks and safety when using technology in everyday life (Skolverket, 2017). Consequently, teacher education in technology must equip student teachers with the necessary skills to teach programming effectively.

There is a lack of research on both technology teachers and technology student teachers' understanding and teaching of programming. However, the small amount of research that does exist shows that technology teachers feel uncertain about how to teach programming, probably because it has been a marginal part of technology teacher education (Sentance & Csizmadia, 2017; Vinnervik, 2022; Webb et al., 2017). Those who taught programming before it became a compulsory part of Swedish technology education in 2018 were mostly computer enthusiasts who had learned to program themselves (cf. Nouri et al. (2020)).

Furthermore, there is a lack of research specifically on student teachers' understanding of the role of programming in relation to the school subject of technology. We know very little about what these prospective technology teachers learn about programming during their teacher education. Moreover, computational thinking (CT) in teacher education, student teachers' perceptions of programming and what constitutes the nature of programming in technology teacher education, are underdeveloped areas of research. However, Tsai et al. (2021) demonstrate that a game-design project helped improve the programming skills and computational thinking of student teachers in Taiwanese pre-service primary teacher education. Other studies, such as Rowston et al. (2022) are more inconclusive and show that technology integration in teacher education, including programming, can be more haphazard. In conclusion, more research is needed that could potentially shed light on what knowledge components need to be in focus to improve programming teaching in technology teacher education.

A framework for technological knowledge and computational thinking

Technology is created by humans to solve problems or fulfil needs and desires (Kline, 2003; Lindqvist, 1987). Technology is not only about artefacts (objects, products) but also about processes, methods, systems, and activities—and *knowledge* about these—either for innovation and production or for use (Bijker et al., 2012; Hallström & Williams , 2022; Mitcham, 1994; Van der Vleuten et al., 2017). Technology is also something fundamentally material, as can be seen in the entire human-built world that surrounds us (Hughes, 2004; Ihde, 1993; Schatzberg, 2018). In line with this, even digital technology that is made up of abstract machine code in ones and zeros—basically Boolean mathematical expressions—must be considered as technology because it requires electrical signals in physical computers for it to work (Denning & Tedre, 2019; Hallström, 2024). Technology can therefore be referred to as the "designed world", in correspondence with the "natural world" as a term for the environment (Blomkvist & Kaijser, 1998).

Technological knowledge is, in a sense, practical and concerned with designing, crafting, and making (Mitcham, 1994). However, technological knowledge is not only practical and hands-on, nor is it merely an application of scientific or other knowledge for practical use, but it is its own area and tradition of knowledge that is related to the designed world and human material culture, in all their variety (Schatzberg, 2018). This means that technological knowledge includes skills and know-how to manage the designed world (procedural knowledge), cognitive and other mental conceptions and theories that make sense of the same (conceptual knowledge), as well as an understanding of the relationship of technology to society and the environment (contextual knowledge) (cf. Nordlöf et al. (2022); Williams (2017)). Technological knowledge therefore concerns the material as well as the abstract, the analogue as well as the digital aspects of the designed world (Hallström, 2024).

Computational thinking (CT) widely applied in computer science, is closely associated with programming skills. In line with the above reasoning, it could also be defined as a kind of technological knowledge. Denning and Tedre (2019) claim that CT encompasses the skills and practices essential for creating computations to perform specific tasks through artefacts, as well as interpreting the world as a series of informational processes. As described by Denning and Tedre (2019), CT also has two further dimensions. One focuses on the mechanics of computer operations, code expression in programming languages, and software assembly into systems. The other dimension focuses on anticipating design needs and considering the user's context. Both dimensions contribute to understanding the purposeful design of technological solutions and artefacts to address challenges (Denning & Tedre, 2019), and both require applying a systems perspective to technological and computational solutions; that is, systems thinking: “a set of skills for understanding, analysing, and working with systems consisting of multiple interconnected elements and exhibiting emergent properties” (Ho, 2019, p. 2764).

Methodology

This article is based on the preliminary findings presented at the PATT40 conference (Perez et al., 2023). The analysis has since been completed, rendering the results more reliable through rigorous categorization validation, including at the aforementioned conference.

To answer the research questions, we used a qualitative method using semi-structured individual and group interviews with student teachers, and a phenomenographic approach (Marton & Booth, 1997) was used to analyse the transcripts and find variation in student teachers' perceptions regarding teaching programming in technology.

Phenomenography

Phenomenography as a research tradition is broadly situated within an interpretive epistemological orientation and focuses on the variation in how a phenomenon is experienced by a group of individuals (Collier-Reed, Ingerman & Berglund, 2009; Marton & Booth, 1997). Phenomenography is underpinned by, among other things, a focus on the relational nature of human experience, a non-dualistic ontological perspective, an explicit focus on the experience of phenomena, and the adoption of a second-order perspective. The result of the research is a set of categories which describe the qualitatively different ways of experiencing this phenomenon and which are logically related in structure and meaning. The categories do not describe how individuals perceive the phenomenon - rather they describe the phenomenon at a collective level (Marton, 1981; Marton & Booth, 1997; Runesson, 2006).

This study investigates the different ways in which student teachers experienced, perceived, or understood *programming in technology education*, here labelled as their ‘perceptions’ of this phenomenon. Even though a phenomenographic study investigates the individual experience, the area of interest here is these experiences taken together; that is, the collective perceptions of a phenomenon (Booth & Ingerman, 2002; Marton, 1981; Marton & Booth, 1997; Trigwell, 2006). Data collected from interviews is interpreted and described by researchers to reshape the individual voice into a collective statement. The perceptions shared by the collective of student teachers is of interest, and therefore all perceptions are collected into a dataset for categorisation (Trigwell, 2006).

The inductive process of creating categories, from these descriptions, involved determining when descriptions about the phenomenon were similar enough to be grouped, and when they were different enough to require separate groupings. This 'set' of descriptive categories forms what is called an outcome space (or space of variation), which contains different groupings of aspects of a phenomenon. Central to this outcome space is that the categories are logically related, typically hierarchically, with each successive category representing a more complex way of experiencing the phenomenon under investigation (Marton & Booth, 1997)

After forming an outcome space, categories were arranged hierarchically depending on both the number of aspects but also the complexity of the aspects, as outlined by Marton (1981). This hierarchical arrangement created a spectrum—a variety—and constituted an intriguing range of understanding in the group of student teachers. It is worth noting that the extent of the range of the established categories is interesting because it provides insights into how great the difference is in how the group as a whole views programming in technology education.

Data collection

Student participating in this study were from three higher education institutions in southern Sweden, enrolled in a four-year program to become teachers for grades 4-6 (pupils 10-12 years old). During one of the eight semesters, they can choose to specialize in either the social sciences or the natural sciences and technology. This part of their professional education aims to enhance their subject knowledge and subject didactics knowledge. The semester includes a five-week course in technology, with the remaining 15 weeks divided among physics, biology, and chemistry. At the time of data collection, the student teachers had completed their technology course, and therefore, it was of interest to investigate what they did and did not discern about the phenomenon of *programming in technology education* and whether and how signs of subject didactics knowledge for teaching programming in technology were manifested. The five-week technology course was taught full-time at these higher education institutions (i.e., 7.5 credits). The course deals with relevant subject theory, together with subject didactics. Among other things, the course's content covers the history of technology and views of technological knowledge, but also construction, mechanics, and technological systems. To ensure that participants had been exposed to similar teaching content, the schedules of the higher education institutions were compared. This established that there were few differences in the teaching content. The proportion of the teaching that involved elements linked to programming corresponds to two full days of the five weeks that the student teachers take the technology course. These elements include the construction of an object which can be controlled by programming. Two data collection sets were used to form a pool of meaning, where the first set is individual interviews and the second is group interviews. The distribution of the participants between individual and group interviews is outlined in Table 1 below.

Table 1. Distribution of participants

Interviews	Participants					Total
Individual	8, including 2 pilot					8
Group	4	2	4	3	4	17
						25

An interview guide was used for both sets of data collection, and they were almost identical, with only a few adjustments made to the second guide. An adaptation was made, given that the data collection on one occasion was conducted individually and the other involved groups, and additional follow-up questions were added to the interview guide for the groups. By using two almost identical guides in two types of interviews, we ensure that the results can be treated equally. The student teachers in the individual interviews came from two different universities and the student in the group interviews came from one of them. Interviews were conducted using Zoom for individual interviews and in person for group interviews. Audio recordings, video recordings, and notes were taken to assist in the analysis process by the first author of this article. Group interviews were planned after the individual interviews. Group interviews allow for in-depth conversations within the group of participants without too much meddling from the researcher. This resulted in allowing more freedom for student teachers to talk, and the researcher played a smaller role than in the group interviews than they did in the individual interviews. At the same time, it can be difficult to capture individuals' in-depth understanding when the researcher does not ask so many follow-up questions. However, the student teachers themselves contributed to a certain degree, posing follow-up questions to each other during the group interviews due to the discussion-like atmosphere (Robson & McCartan, 2016). In both data collection sets, the interview guide included pictures that were used to initiate the conversation. The pictures represented four everyday artefacts: a tumble dryer, traffic lights, a keyboard, and an elevator. These artefacts, familiar to student teachers, were chosen because they can be controlled by programming and they are connected to technological systems, which is an important part of the technology subject in primary schools. The researcher's task during the interview was first to keep participants focused on the phenomenon throughout the interview. The researcher also attempted to gain more depth from the interviewee' answers by repeating the participants' answers and asking whether they would like to elaborate on their answers or add any additional comments or details. Examples of questions that were asked include: “What competences do you think you need to be prepared to teach programming in technology?” “What do you think learners need to know about programming in technology?”, and “What is important that we teach them?” Each individual interview lasted approximately 45–50 minutes, and the group interviews lasted slightly longer. Each participating student teacher was informed about the aim and design of the study and consented to participate. The participants were informed that the study follows ethical guidelines from the Swedish Research Council (Vetenskapsrådet, 2017). The responses were anonymised, and data was managed following the General Data Protection Regulation (GDPR).

Method of analysis

The analysis in this study followed a phenomenographic approach, aiming to achieve a comprehensive and nuanced understanding of student teachers' perceptions of the phenomenon in focus—in this case, *programming in technology education*. The analysis of the transcripts from the individual interviews began with repeated read-throughs, where a researcher, here the first author, reviewed the material to find expressions of the variation between different ways of experiencing the phenomenon. In this way, the researcher first adopts an open attitude to the data which gradually becomes more focused; the researcher then forms a “pool of meaning” pertaining to the entire dataset (Wood, 2000). Within this “pool of meaning”, the researcher identified similarities and differences in perceptions, leading to an initial grouping aimed at discerning variations among the participants’ perceptions of the phenomenon. While the first groupings were being made, all three authors discussed and debated the groupings together. Once the researchers reviewed similarities and differences, they also made descriptions of what constitutes the variation found between the groups as a help when deciding whether the groups should be merged or new groups should be created. The goal of the analysis process was to consistently identify the qualitative variation in student teachers’ perceptions when they describe teaching programming in technology.

From this initial analysis phase of the individual interviews, three categories emerged. These categories describe student teachers’ perceptions of teaching programming as: 1) learning a programming language, 2) solving technological problems, and 3) understanding and describing a technological environment. As the analysis extended to include group interviews, the original categories remained and were strengthened, while one additional category also emerged. In this category teaching programming is described as following instructions in a logical order. The new category had fewer and less complex aspects describing the phenomenon than the previously identified categories and is therefore placed lowest in the hierarchy. A change in the numbering of the categories can therefore be seen below, where categories are described with examples of excerpts that are characteristic of each category.

Validity of the study

Multiple efforts were made to strengthen the validity of the data analysis. Based on the questions posed in the study, the method is appropriate and transparent as there are included extracts from the collected excerpts that show answers obtained in the semi-structured individual and group interviews. The overall questions in the interview guide have been mentioned in the text, but the follow-up questions varied depending on the participants’ answers. To ensure that collected data have been analysed correctly, the categorisation has been questioned and validated several times during the analysis process by other researchers, both in informal discussions and during conference presentations (Collier-Reed et al., 2009).

Since the process of conducting the group interviews confirmed our created categories but also broadened the variety of perceptions, we could assume that we reached saturation in our data in this context and therefore chose not to continue conducting more interviews.

Results of the study

The analyses resulted in four categories describing student teachers’ perceptions of teaching programming in technology education and indicating their potential subject didactics knowledge for teaching programming in technology. The four categories of teaching programming are:

1. following instructions in a logical order,

2. learning a programming language,

3. solving technological problems,

4. understanding and describing a technological environment.

A selection of excerpts is presented below to describe what characterises each category.

Category 1: Following instructions in a logical order

In this category, student teachers describe teaching programming in technology as a series of practical exercises where individuals follow oral or written instructions. What is emphasised when describing the instructions is that it is important to organise them in a logical order and that instructions are used as an input to get a specific output. However, no programming concepts are used, which makes it unclear whether or not they understand the instructions to be synonymous with a programming language. This indicates that the student teachers' focus here is on a structural level—or the order in which instructions are given and how they are followed—rather than on a referential level, where the focus is on the relationship between the instruction and the context in which it is used. The focus on logical order in instructions indicates that some aspects of CT are present.

In the following excerpts, student teachers emphasise the importance of following instructions using a person (analogue programming) to illustrate the logical order needed to make something happen:

> *Cecilia: Yes, but if they're going to work together in pairs, one of them might have to tell the other how to walk, and for them to get there, they have to say all the steps, which is a simple way of showing what programming is.*
>
> *Frida: It's a lot of following instructions and doing it from the top down and this way, […] for example, you're going to guide your friend and give instructions, or you're going to write down an instruction and then the other person will try to follow it, for example, draw something after the instruction.*
>
> *Wera: I think it's good to start with analogue programming. Maybe giving instructions to each other [...] and like this, OK, now you're going to programme someone to brush their teeth. Write step one, step two, step three and then it could go wrong in any way.*

The student teachers in this category focus on what and how to teach programming as 'separate' content, without connections to technology knowledge and to the intentions of programming, so the 'why' question is absent in their descriptions. We interpret that as a gap in their potential subject didactics knowledge regarding teaching programming in technology.

Category 2: Learning a programming language

In this category, student teachers describe programming as a language in the form of instructions using specific concepts, such as loops and expressions. In their descriptions, persons are no longer used as tools to follow instructions and there is a stronger link to computers as receivers of the instructions than to individuals as receivers. The instructions are no longer oral; instead, they use a language with commands (code)—a programming language.

Programming in this category is not seen as a solution to a technological problem, instead, student teachers describe that something happens in the language where you get an output for a certain command (input).

Similarly, as in the previous category, there are traces of CT in the form of instructions following a logical order. Instructions are foregrounded with a focus on the output of the programming language. Still, there is a lack of connection to technological knowledge except in terms of rudimentary systems thinking. The student teachers in this category describe how you can connect components; for example, the computer operates on commands, through a programming language. The following excerpts illustrate this and also describe the need for understanding the language. What follows is an excerpt specifically addressing block programming language:

> *Carin: It's these blocks, it's called block programming and so on. That's what I think because otherwise, it's a too advanced a level.*

> *Chris: It [block programming] contains almost the same thing as programming with code, except that it is blocks, so it contains things like loops and expressions and such things. So, they get to learn it in a simpler way with blocks.*

In the excerpt below we see how the student teacher refers to the computer executing an instruction in the form of commands, and it is about learning to use these commands. A basic level of systems thinking is therefore demonstrated:

> *Daniella: [...] so how to start it on the computer, how to use these commands, how to twist and turn so you get comfortable using it.*

Student teachers' potential subject didactics knowledge is still of a lower order in this category since they mainly focus on teaching a specific language with a specific order on the commands, rather than explaining the use of the programmed artefact outside the computer program, which connects to the intentions of programming in technology.

Category 3: Solving technological problems

In this category, student teachers describe teaching as something that includes the use of a programming language when solving technological problems. In contrast to the two previous categories, here the instructions (the programming language) are no longer in the foreground, but rather represent what can be achieved with the help of the instructions. The output is defined in this category as something linked to a technological solution. Therefore, the category also describes that the student teachers relate programming to technology knowledge.

The student teachers in this category also show a greater understanding of systems thinking, as they describe several components and their close connections. CT is present as descriptions where student teachers make links between programming and problem-solving, which did not occur in the previous category.

The following excerpt shows a continued interest in practical engagement, while also emphasising the necessity of problem-solving:

Clara: […] and technology education is largely about, well, how should I put it, identifying needs, and perhaps finding solutions to those needs, and it's quite challenging nowadays to find solutions to needs if you don't have programming skills.

Daniella: […] But I think that when you program something, it's because it's meant to be some kind of tool, like you want to see something, you want to cook something, you want to dry something. It has a purpose, and that purpose is what belongs to technology. It's not just the fact that it's programmed that makes it technology, but it's what comes after, in a sense.

Hanna: […] programming in technology is more like we program, for example, [...] carousels, making carousels that make them spin and stuff. It's about making things work, you know. So, in technology, it's like, it's a bit more computer-oriented, in a way.

In this category, student teachers emphasise what can be achieved with programming as well as the use of a language. We interpret that as a more developed subject didactics knowledge. The 'why', 'what', and 'how' questions are all present to some extent.

Category 4: Understanding and describing a technological environment

In the final category, the teaching of programming is contextualised as part of society and therefore other aspects are in the foreground compared to the previous categories. Here the instructions are clearly in the background and instead components that can be linked to each other are in the foreground. This indicates a more visible systems perspective, which was only hinted at in the previous categories. Programming is described as part of a larger whole, a human-built apparatus, technological environment, or system. The student teachers show CT in this category by suggesting that teaching should include identifying problems, but also that problems can be divided into smaller sub-problems (decomposition), and the effect overall should be made visible. Björn and Daniella describe this by highlighting several components where they describe teaching that deals with consequences for decisions and actions:

Björn: To understand that something is happening behind the scenes. There's a reason why the lights turn off in the school corridor when no one has been there. It happens automatically, and it's programmed to do so. [...] Many things can be done to maybe save electricity or save water, and it can also contribute to sustainability thinking. Because I think many pupils are very concerned about that nowadays. And through technology and programming, there are great opportunities to address those concerns.

Daniella: No, but what I mean is that everything you learn, it's something that gives you power over your life and how you relate to society. And given that we have many more technological gadgets, we also need to have more knowledge about them and how they work so that we can engage with society and its structures. […] So that they can see that programming exists all around, it's in the traffic light when I go to school, what would happen if something went wrong and what would be the effects in a larger context?

Student teachers' subject didactics knowledge, in this category, is related to the environment where programming is present in today's society. This indicates that student teachers perceive that teaching programming means not only conveying it as a language or as a method for solving problems but also as a way of becoming literate in a technologically intensive society.

Summary of the results

It is apparent in the hierarchical categorisation that there is a wide range of perceptions of teaching programming between the highest and most developed perception (Cat 4), and the lowest and least developed perception category (Cat 1). The lowest category contains fewer and less complex aspects of *programming in technology education*, and then the number and complexity of the aspects of teaching increase with each category.

There are therefore two dimensions that vary between categories:

- the way programming instructions or language are understood, and
- the way technological problems are understood.

The understanding of the instructions and the programming language changes significantly between categories 1 and 2 but is maintained and in the background of their understanding in categories 3 and 4. Thus, while the problem-solving dimension does not appear in the first two categories, it is then visible in category 3 and central in the fourth category.

In summary, the dimensions of variation are related to the identified aspects in the categories. Some aspects appear to be critical in transiting one's understanding from a lower category to a higher one. These critical aspects are essential when it comes to choosing to which category the description should be assigned.

The critical aspect that categorises a description into the second category, instead of the first, is that in addition to emphasising programming as following instructions the student teachers also express *an understanding of a programming language by using specific words and terminology.* For a description to be categorised into the third category, the student teachers also need to show *an understanding of programming as a way of solving technological problems*. The critical aspect that needs to be identified for a description to be placed in the fourth category is that the student teachers show *an understanding that the technological problem impacts on, and is impacted by, our everyday life and society in a broader sense*.

Discussion

This study investigates student teachers' perceptions of teaching programming, after completing their technology course in teacher education.

It appears that the studied student teachers' awareness of the connection to technology education is relatively weak and that there is a predominant focus on instructions and the programming language. This is in line with earlier studies of novice students learning to program (Eckerdal et al., 2005), although it also contradicts findings by Vinnervik (2023), who found that even if technology teachers teach basic coding they focus more on broader technological competencies. In any case, student teachers should not be taught only to program but also to be able to teach technology in a broader sense, where programming is one way of using technology in solving societal problems. Therefore, it is imperative that student teachers reach a more developed understanding of programming, including the problem-solving dimension. This information on the studied student teachers' understanding is important for teacher education to be able to develop student teachers’ subject didactics knowledge in technology during their teacher education, and the variation in perceptions indicates what may be important to emphasise. It is important for technology student teachers to acquire a broad competence that is relevant to and covers knowledge components taught in schools (Doyle et al., 2019; Norström, 2014), but they also need programming knowledge that is specific to teacher education; exactly what this is in a technology education context is not clear due to a lack of research, but the results of this study indicate some such knowledge components, for example, systems thinking.

From the results presented above, it is clear that most of the descriptions collected in the study are categorised in the lowest two categories (Cat 1 and 2) and only a few descriptions are categorised in the highest category (Cat 4). Given that a phenomenographic categorisation is hierarchical, this is interesting because it gives us information about how well the understanding of the chosen phenomenon—*programming in technology education*—is developed among student teachers.

The results show that the majority of student teachers have difficulties demonstrating an understanding of how programming is related to technology, in that they do not see programming as part of the problem-solving dimension, nor do they clearly express an understanding of how technological solutions have a function or purpose in society (Mitcham, 1994; Schatzberg, 2018). However, in categories three and four, some student teachers have more fully developed CT which considers, e.g., design and user needs (Denning & Tedre, 2019), and only in category four do a few student teachers mention conceptions of programming that can be linked to more developed technological systems perspective and systems thinking (Ho, 2019; Slangen et al., 2011). Such thinking is important for developing subject didactics knowledge in technology education and goes beyond merely focussing on what is taught in schools.

The study underlines the importance not only of competence in technology but also subject didactics knowledge for developing programming instruction in the subject of technology. The identified knowledge is an awareness of the three critical aspects—*understanding programming language, understanding programming as a way of solving problems* and *the relation of technological problems to everyday life and society*—as well as two variations: *the programming language,* and *the problem-solving dimension*. Together these aspects imply critical components of subject didactics knowledge that is crucial for student teachers' preparation for their coming profession.

The study thus advocates for a teacher education curriculum that not only imparts practical, procedural skills but also promotes conceptual knowledge and contextual understanding related to technology (Björklund & Nordlöf, 2024). This holistic approach ensures that future technology teachers are well-equipped to address the challenges of teaching programming effectively and adapting to the changing demands of the technological landscape in educational settings and in society at large.

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29.2

Learning to teach and teaching to learn about Robotics at primary level: Professionalization for inclusive technology education integrating Theory and Practice

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Abstract
The professional development of teachers is considered a central task of teacher training and therefore also for teaching technology education in an era of digitalization. The anchoring of technology and digital technologies is becoming a mandatory task in teaching especially due to curriculum requirements and an increasing importance of learning with and learning about digital technologies for dealing with everyday problems (Ministry for Schools and Education of the State of North Rhine-Westphalia (MSB NRW), 2021). The lack of emphasis on technology education in teacher training for primary school teachers in Germany presents a significant obstacle to the integration of technology education into the curriculum. Moreover, the individual decision on the extent to which technology education is addressed in the multi-perspective school subject 'Sachunterricht' leads to insufficient consideration. Furthermore, studies have demonstrated that the self-efficacy and subjectively assessed competencies of teachers have an impact on the inclusion of technology in 'Sachunterricht' (Möller, Tenberge & Ziemann, 1996). It is unclear how (prospective) teachers can acquire and test the necessary competencies to be able to carry out digital-technology and inclusive lessons in an educationally effective manner. To address this question, the present article employs a design-based research approach (Euler, 2014) to test and evaluate theoretical constructs in practice by prospective teachers.

Keywords
Inclusive Education, learning-robots, pre-service teacher education, problem-solving and computational thinking

Introduction
In the context of global challenges such as climate change and energy transition, digital and technical solutions are becoming increasingly important. As Müller and Schumann (2021) demonstrate, the topic of digital technology education in primary schools is gaining prominence, particularly in the field of education (Müller & Schumann, 2021). The acquisition of competencies enabling participation in a digitally mediated world, including an understanding of digital and algorithmic principles, is a key factor in promoting general maturity and social integration (Bohrmann, Weber & Tenberge, 2019). It can be reasonably assumed that the professionalization of educators, particularly in the context of technology-related instruction, will play a pivotal role. The rationale for integrating digital technology into

the educational curriculum can be attributed to its cultural and scientific value, as well as its societal importance in the context of technological advancement and its impact on lived reality (Theuerkauf, 2009).

The significance of inclusive pedagogical practices for diverse student populations is another central focus. Although Inclusion and inclusive education are quite well conceptualized from a theoretical perspective there is a lack of transfer to teachers' professional ways of teaching in inclusive learning environments. This necessitates the integration of theoretical and practical elements in teacher training, encompassing both the academic curriculum and professional development.

The skills needed to participate in the digitalized world are summarized in the 'future skills' model. These include reflective thinking and communication skills (Bates, 2024). In the context of technology education, the two aspects of 'thinking skills' and 'digital skills' are particularly significant. Bates (2024) highlights cognitive skills, which are fundamental to analysing complex problems and developing innovative solutions. The importance of digital skills and the resulting subject-specific use of digital technologies in educational institutions is also emphasized (Bates, 2024).

As a result, it is important to integrate these skills into teacher education. The aim of this research article is to investigate how the integration of theory and practice affects the professional development of pre-service teachers.

The present article falls into five further sections, of which the first will outline the basic concepts addressed. After justifying the requirements of inclusive technology education and problem-solving, section three analyses the teaching setting regarding the role of teachers in an inclusive learning environment, the children's perspective with the needs of children and thinking ahead by integrating modes of representation across a spiral curricular structure. Based on the analysis, this is then placed in the context of teacher professionalisation.

Literature review

Unlike in many other countries technology education at primary level in Germany is integrated in one school subject along with scientific and social scientific education called 'Sachunterricht' (Schröer & Tenberge, 2023). The subject encompasses scientific, social, geographical, historical and technological perspectives on children's living environments in a multi-perspective way. The maxim of teaching 'Sachunterricht' at primary level in an inclusive way provides an essential framework for this fundamental part of education in the German educational system (Schröer & Tenberge, 2023). The multi-perspective character of the subject serves as a potential for inclusive education. Its purpose is to enable all students to explore their environment and examine objects from different perspectives (Academic society for Sachunterricht (GDSU), 2013) ['Sachunterricht' translated from German: social studies]. The objective is to integrate students' prior experiences and their personal contexts, and thereby promoting comprehensive understanding. Therefore, 'Sachunterricht' is designed to provide all students with equal access to education and opportunities for participation in the learning process (Blömer-Hausmanns & Schnell, 2022). Furthermore, 'Sachunterricht' should be implemented in a systematic and structural manner, considering the social and individual differences between students, to ensure that all students have equal access to high-quality education.

Integrating Technology education at primary level aims towards ensuring that students learn elementary forms of technological behaviour and acquire technological knowledge and skills that are relevant to everyday life (Möller, 2002). It is evident that technology is present in children's living environment, as they invent and operate technology and use it to discover and solve problems (Ahlgrimm *et al.*, 2018). Technology education at elementary and primary level is both fact- and child-orientated (Schröer & Tenberge, 2023). Fundamental to teaching and learning technology at an early stage is therefore, to promote interest, enable reflective application and promote the cognitive development of students (Mammes & Zolg, 2015). Therefore, it is necessary to develop differentiated technological ways of thinking, working and acting using exemplary and interest-led objects (Möller & Wyssen, 2018) and to apply methodological and content skills acquired at school in differentiated everyday situations (Landwehr, 2017). Another element is the promotion of a critical perspective towards technology (GDSU, 2013), as students lack an understanding of underlying functional principles in technological artifacts, problems and processes (Mammes, 2001). Finally, Technology education should contribute to the development of awareness of how to utilize technology in an environmentally and socially responsible manner (Steinmann, 2019).

In view of an increasingly complex digital-technological world, the promotion of digital skills in a problem-oriented way, such as the qualified and reflected application, use and active participation in shaping digital media, is essential (Scheibe *et al.*, 2021; Schmeinck, 2022). Problem-orientation serves as a concept for ‘Sachunterricht’ teaching (Beinbrech, 2015). It is characterized by teaching-learning processes, that consider the individual learning requirements of students, can contribute to the development of students' self-efficacy expectations (Steinmann, 2019). The starting point for problem-oriented technological ‘Sachunterricht’ lessons are problems related to the living environment (Finkbeiner & Eibl, 2023). Problem-solving as it’s central methodical approach is also present in all models of Computational thinking (CT) (Kärcher *et al.*, 2024). According to Wing (2006) „computational thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools […]“(Wing, 2006, p. 33). Hence, computational thinking in digital and analogue environments is regarded as a qualification for social participation and is becoming increasingly important in schools (Wing, 2006; Senkbeil *et al.*, 2019). The competencies of Computational thinking are interdisciplinary and fundamental to various domains of knowledge that enable (computer-aided) problem-solving (Senkbeil et al., 2019). Computational thinking encompasses a wide range of competencies, which are described in the competence model of the International Computer and Information Literacy Study (ICILS) (Fig. 1).

The model demonstrates that the integration of content-related competencies, problem-solving abilities, and digital literacy skills can be promoted through CT approaches. CT can contribute to the development of ‘future skills’ in students. The acquired CT competencies facilitate students' future professional and social lives by fostering the development of problem-solving abilities with digital relevance (Kärcher et al., 2024).

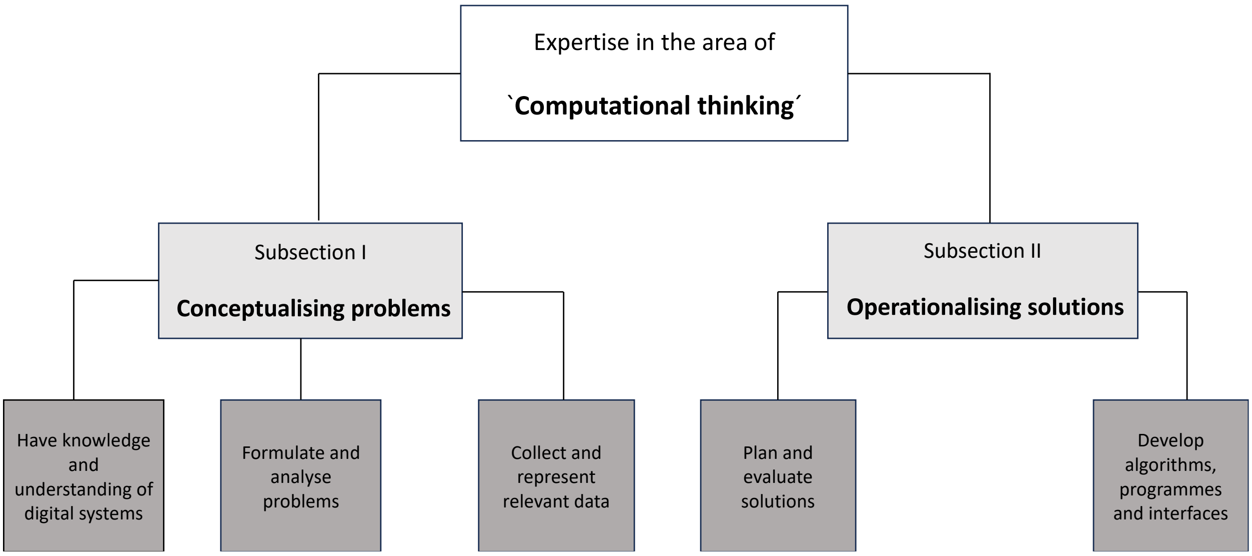

Figure 1: CT- competence model (Senkbeil et al., 2019, S. 101). Translated by Schröer et al., 2024.

The two domains the competence model comprises – conceptualization of problems and operationalization of solutions – extend beyond the mere utilization of hardware and software. They are concerned with the resolution of problems which frequently occur through the development and application of algorithms, which are then made accessible to digital systems, such as computers.

The initial stage of this process is the conceptualization of problems. This necessitates an understanding and processing of the problem in question, as well as the development of potential solutions. A fundamental prerequisite for this is a comprehensive grasp of digital systems and their interactions. It is essential that students learn to identify the characteristics of digital systems and their interconnections. This should facilitate an enhanced comprehension of both digital and analogue realms, and subsequently inform the resolution of problems. This understanding enables students to conceptualize problems and to describe the tools and systems they employ. In the formulation and analysis of problems lies another aspect of the competence model that is geared towards enabling students to divide problems into smaller components, and to integrate encountered solutions with new ones (Senkbeil et al., 2019). Another aspect of this competency is the representation and collection of relevant data. As a result, students can assess the efficacy of proposed solutions.

The second area of focus – 'Operationalizing solutions' – encompasses the creation, implementation, and evaluation of algorithmic problem solutions. This includes planning, implementation, testing, and assessment of solutions regarding their transferability to everyday problem-solving scenarios (Senkbeil et al., 2019). This encompasses the capacity to define requirements in relation to intended solutions, as well as the ability to assess algorithms and solutions from multiple perspectives using criteria-based evaluation. The second aspect, "Development of Algorithms, Programs, and Interfaces" primarily concerns the conceptual development of algorithms and programs, as well as their automatization and execution. The development of Computational thinking can be facilitated in primary education using programmable digital technological artifacts such as microcontrollers like the Calliope mini™

and learning robots (e.g. BlueBot™). Learning robots, unlike typical robot toys, are characterized by their integration into educational environments guided by theoretical and empirical frameworks (Janicki & Tenberge, 2023).

The BlueBot™ is a robot designed for use in grades one to six (Bohrmann et al., 2019). The upper surface of the robot contains the controls, which enable forward and reverse motion, as well as left and right turns. Additionally, there is a pause, a reset, and a start button. BlueBots™ can be employed in authentic learning environments. They enable students to adopt positions that facilitate optimal imitation of the BlueBot™ movements (Miková *et al.*, 2022) and offer educators the flexibility to differentiate their instruction in a multitude of ways. Routes can be adapted to suit the needs of the learners, and the number of steps in the process can be increased or decreased as required. Furthermore, the incorporation of a notation of the sequence of instructions can be implemented in various ways (Bohrmann et al., 2019).

The microcontroller board Calliope mini™ represents a significant advancement in the field of informatics teaching and learning, particularly for students in their third year of schooling. Its objective is to illustrate and promote the accessibility of programming. By providing a straightforward and multifaced programming environment, it facilitates a gradual introduction digital technology. The Calliope mini™ is distinguished by the integration of a multitude of components, already present on the circuit board. These include LED displays and microphones, enabling students to undertake a diverse range of experiments and projects without the need for additional hardware. The programming is carried out via a software application executed on a laptop or tablet computer. The Calliope mini-board contributes to the deepening of understanding of digital technologies and the stimulation of interest in informatics among students of all age groups (Bergner & Leonhardt, 2019).

Programmable technological artifacts in general are considered to offer the potential to integrate digital media into inclusive teaching and learning (Wassermann, 2021). They have the capacity to enthuse students about informational learning (Tengler, 2020). The utilization of learning robots and microcontrollers in inclusive science education enables a transformed interaction with educational content, as robots possess a particularly motivating effect (Wassermann, 2021). The collaboration with learning robots is particularly fruitful in integrating productive action with Computational thinking. The objective is to guide students towards abstraction of problems through interaction with learning robots (Bohrmann et al., 2019).

The integration of learning robots into 'Sachunterricht' becomes increasingly important in recent years (Tengler, 2020). As innovative educational tools, they offer the potential to promote algorithmic thinking and influence motivation and interest (Wassermann, 2021).

The perception of autonomy and competence are key aspects of motivation. Haase (2017) posits that the consideration of these aspects can have a profound motivational impact. Making independent decisions and experiencing success enhances the engagement and interest of learners. A study by Bieg and Mittag (2009) indicates that there are both subject-specific and gender-related differences in interest in learning robots. In addition to the academic influences, familial support is also a significant factor (Bieg & Mittag, 2009). Lichtblau (2014) emphasizes that a supportive home environment can enhance students' interest, motivation and engagement in the academic context (Lichtblau, 2014). Another factor influencing motivation is the relationship between teachers and students. Bieg, Backes and Mittag (2011) demonstrated that a supportive and encouraging teacher-student relationship enhances intrinsic motivation among students. An open and respectful teacher-student relationship fosters a positive learning environment that can enhance students' interest in 'Sachunterricht' (Bieg, Backes & Mittag, 2011).

It can be concluded that prospective teachers of inclusive, problem oriented 'Sachunterricht' are given a wide range of responsibilities. The extent to which prospective teachers are prepared for these tasks is discussed below.

Problem statement – Aspects that define a professional teacher

In the preceding explanation, characteristics of inclusive digital-technology education 'Sachunterricht' have been delineated. The heterogeneity of learners is becoming increasingly pivotal in the design of teaching and learning (Dexel & Kratz, 2022). Digital-technology education must be firmly established within the curriculum of primary schools to meet the changing demands of society and to promote the ability to apply knowledge, motivation and interest in the field of informational technology. This should be achieved by encouraging students to learn *with*, *about* and *despite* digital media (Döbeli Honegger, 2017; Tengler, 2020). It is therefore essential to develop Computational thinking abilities, as they are applicable across different subject areas and encompass both computer-assisted and independent analogue problem-solving skills (Senkbeil et al., 2019). The most positive motivational experience associated with the educational use of learning robots is essential for students to experience autonomy and competence and for them to develop a long-term interest in digital technology (Wassermann, 2021; Haase, 2017).

Considering the ongoing debate surrounding the professionalization of teachers in a digital era, we assume a fundamental role for the design of technology education especially at primary level. The professional conduct of teachers in technological 'Sachunterricht', both within the context of the school curriculum and particularly in the context of teacher training, is characterized by a high degree of complexity. It is not only necessary for teachers to gain subject-specific knowledge from different academic disciplines to deliver effective lessons, but they must also engage in a nuanced examination of the characteristics of the subject area of technology.

These challenges underscore the importance of a theory-practice integration that is both quantifiable and qualitative, and that assesses the impact of such integration on the professionalization and self-efficacy of prospective teachers. These considerations inform future teacher education, at all stages. The issues are addressed in this article in the context of three key themes: (1) *teachers' role in an inclusive learning environment*, (2) *integrating modes of representation across a spiral curricular structure*, and (3) *an empirically represented children's perspective to the consideration of their needs*. These themes are discussed and then brought together for a final analysis in the conclusive chapter.

Integrating theory and practice

The following section integrates considerations with the practical experiences that three pre-service teachers gained during their apprenticeship. During a micro-teaching experience that is considered to have positive effects on students' knowledge and self-efficacy in an academic context (Schröer & Tenberge, 2022), technology related 'Sachunterricht' was planned in a seminar and carried out in accordance with the criteria set out for the micro-teaching context. The experiences were evaluated and systematized based on the aforementioned theoretical considerations. According to the methodical frame of design-based-research, the systematized evaluations were used as a *beta-testing cluster* (McKenney & Reeves, 2019) for further development of the intervention.

Three spiral curriculum units on learning robots were taught. To facilitate a more detailed planning of the teaching units, the students' prior experiences were evaluated in advance using self-developed assessment tools developed by the research group for teaching and learning Social and Scientific Studies with Special Needs Education at Paderborn University. These findings were then used to inform the design of the teaching units.

The intervention was conducted during the school entry phase. The BlueBot™ was selected as a shared instructional object. The objective of the intervention was to develop competencies in *chain-based* programming using path problems. A subsequent instructional unit was conducted in a third-grade classroom. The BlueBot™ was employed as a shared learning subject into enhance students' problem-solving abilities (Schröer & Tenberge, 2023). Building upon this unit, a subsequent unit was conducted with the microcontroller Calliope mini™. The acquired technological abilities were revisited and expanded upon in the context of block-based programming.

The following section will examine the role of teachers in said inclusive learning environment and the children´s perspective or how to consider needs in a digital-technology learning environment. Both will be revisited in the third perspective: Thinking ahead - integrating modes of representation across a spiral curricular structure. This will be done with a view to analysing the professionalisation of prospective teachers for technology-related ‘Sachunterricht’.

Teachers’ Role in an inclusive learning environment

It has become evident that there are significant shortcomings in the quality of teaching and learning in Germany, particularly in primary schools, following the global pandemic. The pandemic has demonstrated that many primary school teachers lack the necessary skills to effectively integrate digital media and promote independent learning (Maennig-Fortmann & Hamm-Pütt, 2021). In the field of education, there is a constant demand for the teaching curriculum to be updated and modernized, particularly in terms of digitalization. This requires teachers to possess a range of skills, including technological, pedagogical and digital competencies (Haase, 2017). However, these skills are often not adequately addressed during the training of prospective teachers at German universities, with further training opportunities being insufficiently available (Drossel *et al.*, 2019). This leads to the question of how prospective teachers can be trained to meet the aforementioned expectations.

In the context of Paderborn University’s teacher training program, students can further their education and theoretical knowledge in the field of digital and technology education, with a particular focus on the practical application of their learning.

The instruction conducted within this framework was planned with a focus on learning through shared objects, as advocated by Feuser (2011). According to Schröer and Tenberge (2022), a shared learning object is essential for inclusive science education. Through this shared learning object, equal and equitable participation of learners is facilitated (Schröer & Tenberge, 2022), allowing all students to engage in inclusive instruction. In the context of the aforementioned instruction, students collectively interacted with the BlueBot™ and the Calliope mini™.

To fulfil the requirements of inclusive teaching, the students' previous experiences were assessed at the beginning of each teaching unit. This approach is consistent with the assumption that building on students' experiences and knowledge are fundamental to the design of 'Sachunterricht' lessons (Schönknecht & Maier, 2012). According to Buholzer's (2006) model of diagnosis and support, building on previous experiences is included in the diagnostic skill set. This phase among the diagnosis and support cycle serves to collate information on the students' previous experience in key learning areas, thus enabling the identification of their level of performance regarding learning prerequisites, learning processes and learning statuses. This information is used to adapt teaching in the most effective way (Buholzer, 2006). The survey of prior experience was carried out with the help of a test around computational thinking. Upon analysis of the results, it was determined that the students had already acquired prior experience with the fundamental principle of input, processing and output. Consequently, the lessons were tailored to align with the students' competencies. In addition to recording previous experience, the lessons were adapted to align with the students' learning level. The introductory task, "*human robots*", which was previously conducted in an intervention, was adapted regarding *block-based* programming.

After the students had completed the adapted introductory task, the other tasks were carried out using a station learning design. The tasks and problems could be completed independently of each other. The order of the tasks could be chosen by the learners in partner or group work, so that individual learning paths were chosen based on interests and abilities and the children's learning behaviour could be coordinated easier (Reich, 2014). The station learning method was also used in the unit with the Calliope mini™. The individual tasks were separated by colour and space and labelled accordingly to enable students to make an informed choice.

In the interest of inclusive teaching, individual support measures such as hint cards were made available. Different types of tasks with different levels of difficulty allowed for differentiation in the teaching of technological 'Sachunterricht'. Pupils were able to choose between individual tasks for programming with the Calliope mini™. The individual tasks differed in terms of performance level, implementation, presentation, instructions and finding and correcting errors in a programmed presentation. Differentiating the tasks allows for inclusive teaching that is designed for all children. These lessons are based on each child's learning needs, so that each child's skills can be developed (Kaiser & Seitz, 2020).

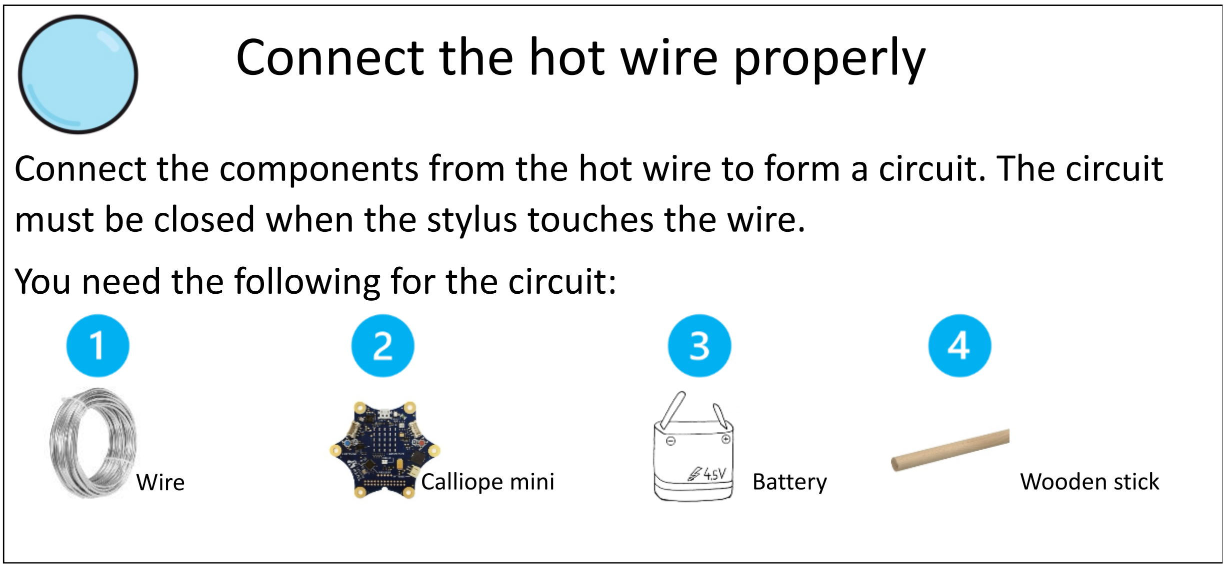

Figure 2: Hint Card Calliope mini (Schröer & Tenberge)

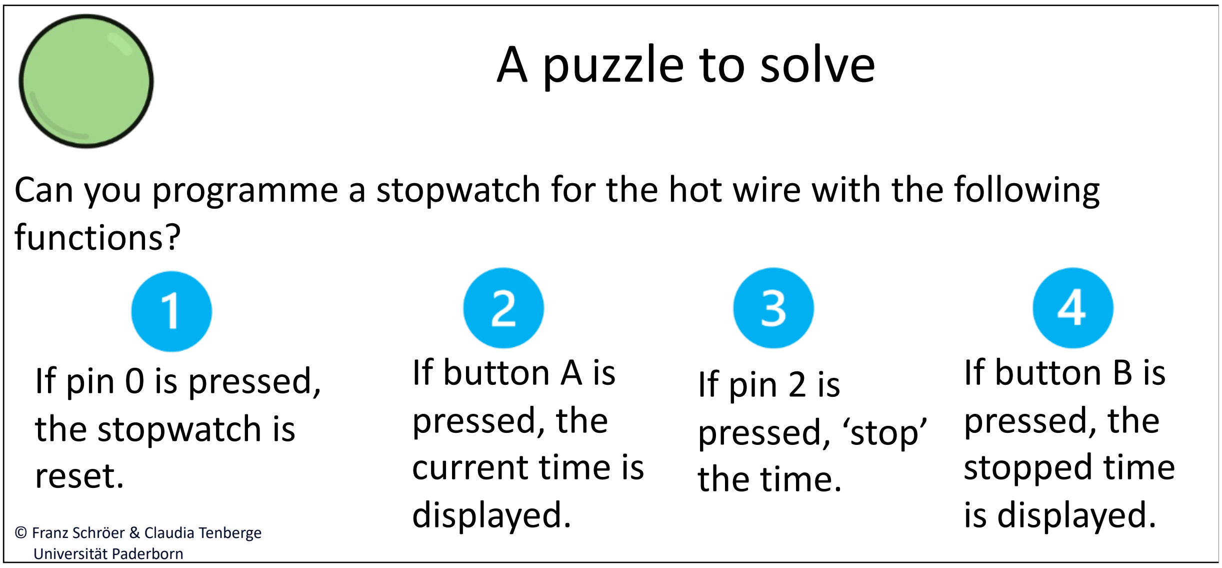

Figure 3: An open problem-based task (Schröer & Tenberge)

The hint cards could be used to solve any problems that arose, allowing for individualized further work. The choice of whether to use one or more of them was left to the students but scaffolded by the teacher. This allowed teachers to support students individually so that a higher level of performance could be achieved without anticipating the solution (Kaiser & Seitz, 2020).

Scaffolding measures were also in place in the classroom settings. According to the scaffolding framework of Van de Pol et al. (2010) the areas of fading and transfer of responsibility to the learners were emphasized. Fading refers to the needs-based reduction of support by the teacher which occurs in interaction with the learner's level of development and diagnostic behaviour, as well as the transfer of responsibility. Complementary to fading, the transfer of responsibility involves handing over responsibility by having learners perform tasks increasingly independently (Van De Pol, Volman & Beishuizen, 2010). The teacher transferred responsibility to the learners by, for example, allowing them to choose the task formats. Learners received support during this phase of the work if they needed it. When the teacher identified need for support in the situation and was able to provide individual support to the students.

The station learning tasks were carried out by the students in partner and group work. This included working in pairs on programming with the Calliope mini™ and in groups of four with the BlueBot™. This ensured collaborative learning and peer-communication, which goes beyond working in groups and puts particular attention to individual responsibility, mutual support, appropriate use of social skills and reflection on group processes (Scheidt, 2017). Of relevance here is a positive interdependence, which assumes that collaboration only works when there is a common goal.

Because of the common goal and the variety of implementation and operation, the aspects of cooperative learning are fulfilled. The common goal was always given, so the task formats required students to work together, try things out and discuss their solutions. Furthermore, the teacher ensured that the students took turns in programming by entering the code sequence in BlueBot™ or by inserting the codes in the correct order in the programming environment.

Children's perspective: How to consider children's needs in a digital-technology learning environment

Methodological and teaching and learning possibilities for taking learning needs into account are to be outlined in the context of testing needs-oriented inclusive 'Sachunterricht'. The results of a questionnaire survey, that is supposed to measure the satisfaction of basic psychological needs (autonomy, competence and social relatedness) (Ryan & Deci, 2000) in different situations or in interpersonal interaction (Schröer & Tenberge, 2021) serve as a basis for the conception of this lesson.

The unit first introduced the new topic of 'robots' with two video impulses. Subsequently the fundamental principle of input, processing and output was developed and the BlueBot™ as a device was introduced. Afterwards, the students worked in groups for three lessons on various problem-based tasks. The design of the lessons considered different aspects that aim at satisfying basic psychological needs. On the one hand, students should learn together in cooperative and pedagogical playful forms and achieve competence to satisfy their need for social relatedness. In addition, differentiation measures and self-control aimed to satisfy their need for competence (Ryan & Deci, 2000; Haase, 2017). This need was also addressed through constructive feedback and a transparent presentation of learning progress and task limitations (Haase, 2017). The open and practical concept of explorative and problem-oriented teaching, taking into account the relevance to everyday life, was designed to meet the need for autonomy (Tenberge, 2002). In addition, station work, and the associated freedom of choice and self-control supported the need for autonomy. Furthermore, autonomy is supported by the possibility to design one's own tasks and promoted self-regulation of the learning process, thus preventing over- or underchallenge (Wood, Bruner & Ross, 1976).

The lessons were evaluated in subsequent interviews, followed by a qualitative content analysis. This determined whether the expression of students' needs was consistent and whether the intended measures promoted the consideration of needs. The students' statements suggest that the manifestation of the desire for a particular need to be considered is differentiated at different times. Furthermore, students make differentiated statements during the interviews regarding the desired consideration of needs.

During the interviews, the students mentioned the varied and hands-on tasks as positive aspects of the lessons. Furthermore, the pupils positively emphasized the perceived freedom of choice through the different solution paths. The teaching methods used to satisfy the need for competence were recognized by the students. Particularly hands-on tasks were emphasized by the students and underlined by the desire to expand their own procedural knowledge. In this way, the students explicitly demand the experience of competence - also in real-life situations. In addition, the students say that longer periods of reflection would increase their experience of competence. The cooperative and pedagogical forms of playful learning were designed to satisfy the need for social relatedness. These forms of learning are evaluated differently by the students. Most students describe the collaborative activities as enriching and successful. However, two students limit the successful characteristics of collaborative learning and express the wish to work individually more often in subsequent learning sessions, as there was no collaborative learning within the group. This shows the importance as a teacher of constantly reflecting on group collaboration. It also shows that simply offering a needs-based arrangement is not enough to meet students' needs. This shows that individual, contextual and institutional influencing variables control the consideration of needs (Helmke *et al.*, 2007).

Implications that can be described for the actions of (prospective) teachers include an appreciative attitude and commitment to all students as constitutive characteristics of needs-based teaching. In the unit described, the appreciative attitude is conveyed through the experience of attention. However, the constructive discussion of the students' tasks and solutions and the resulting support show the appreciative attitude of the teachers. In addition, feedback and guidance are essential features that a teacher should establish in his/her teaching to respond appropriately to students' needs and to facilitate inclusive learning.

The feedback given to students during the learning process should be formative assessment and feedback that allows students to adapt their learning strategies and draw conclusions for solving the task (Haase, 2017). On this basis, advice that is targeted to specific issues and can be used in a sustained way has also been shown to be effective (Hattie, 2014).

Taking these characteristics into account, feedback and counselling can promote students' self-efficacy (Haase, 2017). To implement these characteristics in the classroom, focused preparation using the characteristics of needs-based teaching described above as guiding principles is essential.

Thinking ahead – integrating modes of representation across a spiral curricular structure

According to Bruner, people actively construct meaning for themselves, considering cultural resources and social interaction. In addition, the consideration of psychological development makes it possible to discuss a multidisciplinary content (Bruner, 1971). This principle also characterizes the educational intervention carried out. It is designed as a spiral curriculum to ensure that it can be linked to the cognitive abilities of the students (Bruner, 1976). The spiral structure of skill development is characterized by the fact that a learning object is first explored at a basic level and with increasing complexity later (Haste & Gardner, 2017). Along this spiral of complexity, both specific and interdisciplinary skills and ways of thinking are promoted according to the level of education (Gillen, 2013; Hardy et al., 2017). At the same time, the use of disciplinary language is sharpened (Plinz, 2021). These competencies are developed experientially and actively using different representational modes (Hardy et al., 2017; Haste & Gardner, 2017). Bruner establishes the enactive, symbolic and iconic form of representation for intellectual growth (Haste & Gardner, 2017). Each form has its own way of representing processes (Bruner, 1971). While knowledge through the enactive mode of representation is gained through one's own actions, the development of knowledge based on the iconic mode of representation is characterized by reference to images and graphics (Käpnick & Benölken, 2020). Finally, knowledge acquisition through the symbolic mode of representation is characterized by the acquisition of knowledge through different symbol systems, such as spoken or sign language (Käpnick & Benölken, 2020). Bruner emphasizes that different modes of representation should be aligned with cognitive and psychological development. However, they do not build on each other sequentially, so that the ability to visualize a product of action does not mean that the actions to achieve the product can also be performed (Bruner, 1971). Based on Bruner (1971), Gebauer and Simon (2012) identify two further basic levels. The communicative-interactive mode is intended to provide access to the environment through media such as the body and spoken language or prosody (Gebauer & Simon, 2012). The sensory development of a learning object takes place through sensory experiences such as touching, feeling or smelling and refers to the Montessori method (Gebauer & Simon, 2012). This expansion of modes of representation offers further potential for inclusive 'science education'. The development of learning objects on the different modes provides opportunities for all students to connect and ensures student participation in common learning objects (Feuser, 2011). This is supported by the optional use of different modes of representation (Gebauer & Simon, 2012), so that the programs can be selected according to individual needs. The choice of representation is not based on age, but rather on education and experience (Haste & Gardner, 2017). In this way, different cognitive and emotional stimulation can be achieved in students, and students become constructors of their individual learning process (Blumberg & Mester, 2017; Lipowsky, 2021). These theoretical principles are fundamental to the conceptualization of the tested instructional interventions. Along the spiral curriculum, the three learning processes are addressed: 1. acquiring and refining knowledge, 2. transforming knowledge to use it for new tasks, and 3. evaluating whether the transformation is appropriate for the intended purpose (Bruner, 1976). Different modes of representation are used and – as already noted by Bruner (1971) – interacted with each other. This interaction is illustrated in the model of "spiral curricular linking of modes of representation in interaction".

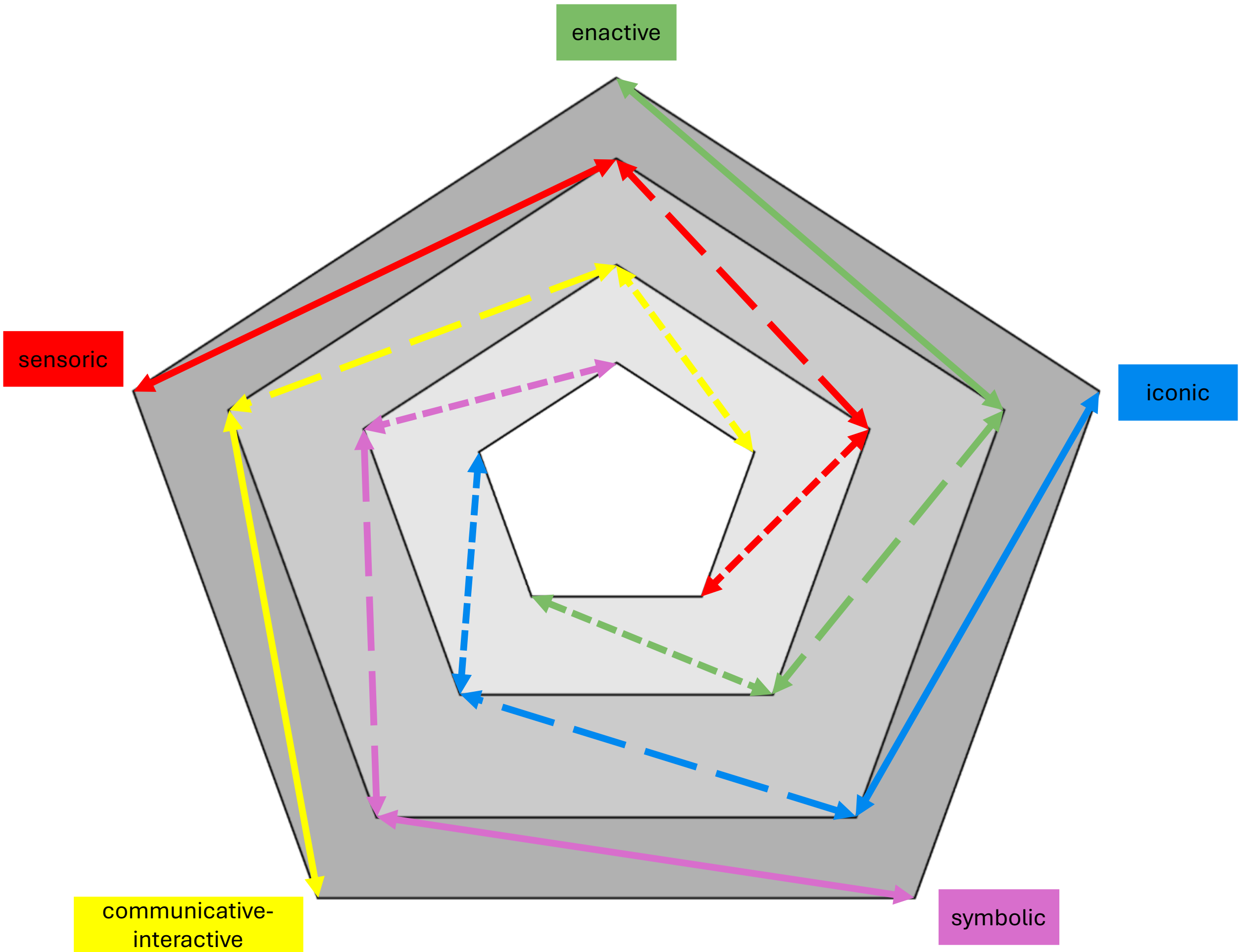

Figure 4: "spiral curricular linking of modes of representation in interaction" (Schröer et al.)

The model brings the five modes of representation of education together and illustrates their possible spiralling interrelationships. The levels of representation 'communicative - interactive', 'symbolic', 'sensory', 'iconic' and 'enactive' are labelled at the corners of the outer pentagons. The continuous colour coding of the arrows and circles makes it clear where each mode is represented in the model. The arrows connect the different levels of representation. The model shows that one form of representation can be linked to any other form. Within these links there may be quantitative differences in the number of linked representations. The levels of representation can be related to each other, and a change of representation is always possible in all directions. The spiral arrangement in the model illustrates that a spiral curricular acquisition of knowledge (Bruner, 1976) can be supported using different modes of representation in combination. The use of different modes of representing a learning object enables challenging learning on a common object (Feuser, 2011) for all students. The model of 'spiral curricular linking of modes of representation in interaction' shown in Figure 4 serves to illustrate the reciprocal linking of modes of representation across subjects and topics. This model can be used to sort educational tasks thematically and to evaluate the modes of representation involved. The multidimensional structure (see Figure 5) is added to the model to make the direct links between the modes of representation more concrete. In addition, teaching and learning arrangements are possible in which more than two modes of representation are combined in a pedagogically effective way. Figure 5 describes examples of different combinations of two modes of representation. For example, the "communicative-interactive" mode can be linked to the "symbolic" mode by transferring *verbal commands* that a learning robot or microcontroller is to execute to *symbolic programming language*. A quantitative extension of the examples in terms of the number of representation modes included is possible, but not intended at this point.

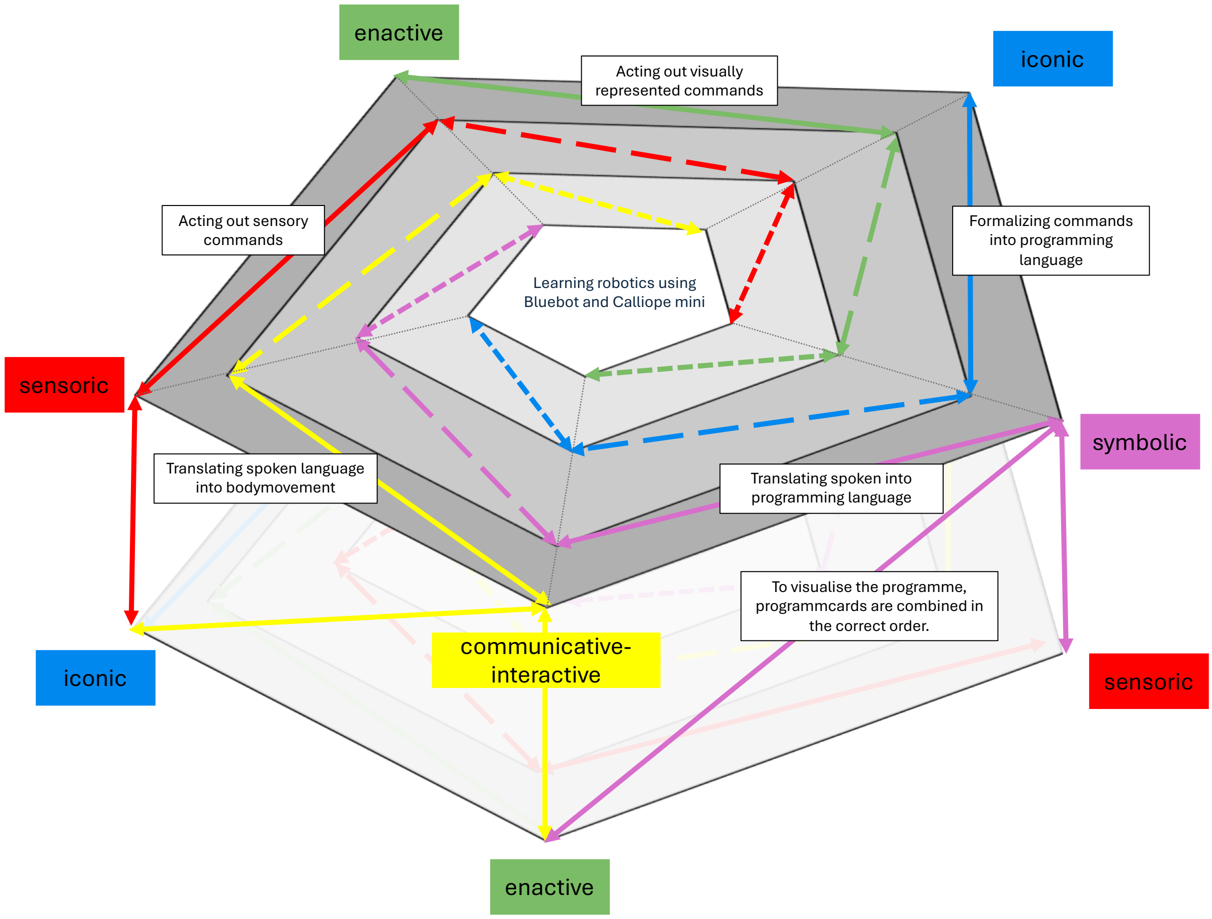

Figure 5: Exemplary linking between the modes of representation using the example of a spiral-curricular digital-technical education (Schröer et al.)

The combination of the different modes of representation, theoretically in the model and practically in the teaching situations, shows that the combination and use of the different modes of representation enables all pupils to participate in the object of learning. The differentiation of the level of abstraction makes it possible to switch between the modes of representation. In this way, students who use a supposedly more complex form of representation and students who use a supposedly less complex form of representation can exchange knowledge.

During the lessons in which the BlueBots™ learning robots are used, the students' actions as well as the presentation of the information on the worksheets are primarily assigned to the enactive and iconic modes of representation. The iconic images of the symbols on the tasks are identical to those on the BlueBot™ buttons. This allows students to make a direct connection between the iconic representations. The solutions are designed to be enactive, as the problems are tested and evaluated with the learning robot. The worksheets are designed so that the solutions can be documented in diverse modes. The design of the task description focuses on reducing the amount of written language and supporting comprehension through iconic representations. This creates the first moments in which different modes of representation are combined. Furthermore, the modes of representation are linked when, for example, the students visualize a program by first arranging symbolized programming commands in a chain of commands. Overall, the teaching intervention is designed with a special focus on communicative interaction between the students and helps to encourage them to engage in dialogue. This can be noticed, for example, when solutions are discussed, evaluated or adapted.

In addition, Computational thinking skills are also organized in a spiral curriculum in the teaching arrangements described. The use of BeeBots™ is already possible at pre-school level in order to introduce skills such as questioning or first if-else connections (Ministry for Children, Family, Refugees and Integration of the State of North Rhine-Westphalia/ Ministry for Schools and Education of the State of North Rhine-Westphalia, 2018). This topic has not yet been tested in our research group. For this reason, this part of the spiral curriculum teaching concept is not reflected at this point.

It can be followed by learning arrangements with BlueBots™ and possibly other learning robots in school years 1 and 2. Building on the pre-concepts, the competence domain of Computational thinking should be improved. The BlueBot™ can be used to solve path problems. The path problems are conceivable in different contexts, such as in Figure 6: 'BlueBot™ as a bus driver'.

Figure 6: 'BlueBot™ as a bus driver' ©Schemel (2023)

Students must first recognize and understand the problems presented (Wing, 2006). Students then need to devise and program different steps to solve the problem in a way that encourages algorithmic thinking (Wing, 2008). Decomposition into sub-problems or abstraction of the given information may also be necessary (Barr & Stephenson, 2011; Hong, Qian & Yang, 2021). For example, if students are asked to deliver parcels to different houses in the 'BlueBot™ as a parcel deliverer' task, considering a delivery route individually as a subproblem may reduce the complexity of the problem. However, the BlueBot™ can also be used to promote the reflective consideration of an individual algorithmic product as well as the identification of errors and their solution (Hong et al., 2021). In school years 3 and 4, these skills can be further developed using the Calliope mini™ microcontroller.

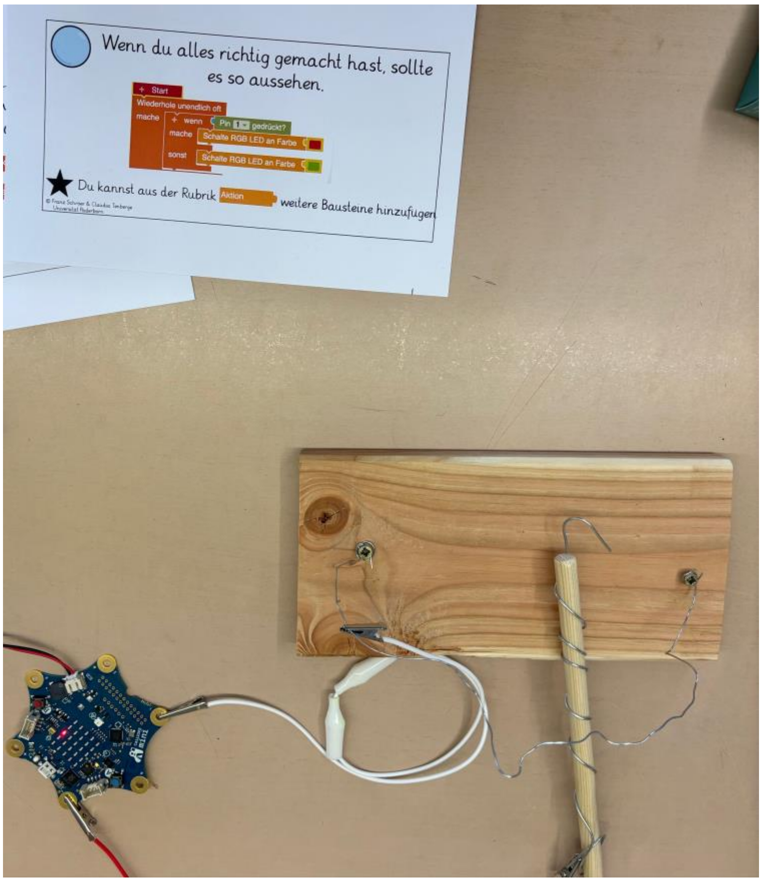

Figure 7: Calliope Mini as hot wire ©Schneider (2024)

The lesson is designed in such a way that the individual stations are first presented verbally and in a linguistically sensitive way using the communicative-interactive mode of representation. Furthermore, the symbolic mode of representation is considered when, for example, illustrations are linked to the written presentation so that the iconic and symbolic modes of representation are accessible. This linking enabled students to reread and repeat technological terms and relevant representations. Overall, the symbolic mode of representation is particularly important when working with the Calliope mini™ because the programming blocks must be represented and linked symbolically. This written representation of the programming blocks means that reading skills become an essential pre-requisite. This is linked to the communicative-interactive dimension when, for example, different verbally expressed programming steps are translated into symbolized programming blocks. The inclusive design of the lessons enables all students to participate by supporting each other within the individual competencies of each student. The active, digital-technical way of working provides an enactive approach to the subject and opens further opportunities for participatory involvement in the lesson. The Calliope mini's various sensors allow it to be used in a variety of ways, for example, as a sensory representation through the acoustic output of different sounds. During the lesson, students are given hint cards to actively construct their own knowledge. These cards include images and provide access to the subject through the iconic form of representation.

Computational thinking skills already acquired are used and further differentiated along the spiral curriculum. The range of skills is broadened by using the Calliope mini™ and block-based programming. The problems of other concepts need to be identified and understood through the systematic processing of information (Wing, 2006, 2008). The previously acquired competencies form the basis for the specification of digital-technical competencies. In addition, students learn a new, block-based form of algorithmic solution methods and increase their ability to deconstruct problems and solve them algorithmically. Furthermore, more differentiated and complex errors and their identification and solution become possible (Hong et al., 2021). This increase in complexity arises, for example, from the Calliope mini's multiple sensors and actuators, and realizes the theoretically described spiral curriculum of Computational thinking skills in the classroom. In addition, it allows for connectivity to further specify Computational thinking competencies across educational levels in lower secondary school.

Therefore, it can be concluded that both the *modes of representation* and the *content-related Computational thinking competencies* can be built up in a spiral curriculum in the intended teaching arrangement and can provide a link to lower secondary level.

Conclusion - Challenges for professional development

This article examined the urgency to further establish digital-technology education and prepare teachers professionally for this school practice. Various concepts of teaching and learning are reflected from three perspectives and the challenges of linking theory and practice are examined. The results can be regarded and discussed against the background of the guiding question: "What are the effects of linking theory and practice on the education, self-efficacy and professionalization of (prospective) teachers in digital-technical ‘Sachunterricht’?

The results show that the role of the (prospective) teacher in inclusive digital technologies ‘Sachunterricht’ is crucial to a successful implementation. Teachers must integrate both their content and pedagogical knowledge into the planning and implementation of technology education lessons. Particularly regarding a perspective towards inclusive education, it becomes evident that a meaningful pedagogical approach is important to do justice to the individual needs and potentials of *all* pupils. The reflexive analysis of the lesson illustrates the heterogeneous characteristics of the implementation of an inclusive lesson. The results show that an increase in learning can be achieved for all pupils and that pupil participation increases.

Against the background of the article's guiding question, the problems that arise in connection with the theory-practice connection were to be analysed and adapted. The central difficulty was that dealing with teaching materials can be challenging in comparison with dealing with analogue learning materials. In addition, the indispensable literacy development of the content makes it difficult to use the Calliope mini™. The disadvantage of pupils with lower literacy skills needs to be reduced by language sensitive characteristics of the learning environment. So that all pupils can participate in a common learning object, such as following the codes. To this end, alternative colour patterns can be used as a support measure.

To be able to meet the demands of inclusive technology education ‘Sachunterricht’, prospective teachers need theoretical background knowledge. Training and seminars offer opportunities to develop digital literacy and to build this knowledge. Seminars in a university context combined with micro-teaching elements promote the development of individual competencies. The theoretical background knowledge acquired, and the experience gained in teaching can be used for topics and ideas for empirical final thesis's and thus be examined in greater depth. In terms of evaluating the effectiveness of the measures, these positive effects show up in terms of the increase in teachers' skills. The subjective assessment of the students also suggests that the lessons can promote motivation and interest in technological problem-solving. Further empirical research on students' motivation, interest and competence growth in technological problem-solving can be justified accordingly.

Regarding the question "To what extent does the theory-practice connection affect the professionalization of (prospective) teachers?", it can be stated that the lessons carried out effect the self-worth of (prospective) teachers and can positively influence it, thus contributing to the professionalization of the teacher. It can help to anticipate *"stumbling blocks"* and difficulties for future learning units and to better assess the necessary specialized knowledge for technology education in a digitalized living environment.

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29.2

Making pedagogy for spatial literacy: a case study of an origami workshop in an after-school makerspace

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Abstract

Spatial skills are crucial to STEM disciplines and involve a variety of cognitive processes and skills related to visualising, reasoning and communicating about spatial relations. Particularly in the primary school years, attaining 'spatial literacy' gives children a valuable set of skills and knowledge that can aid them in successful participation in STEM subjects. However, it is poorly understood what constitutes spatial literacy for primary school age children. Furthermore, research into pedagogy for spatial skills is limited, with training interventions often resembling psychometric tests. Therefore, it is pertinent to explore which spatial skills and knowledge are most important for primary school age children to develop and how pedagogy could look to help children to attain spatial literacy. Maker education provides an integrated and design-based approach to learning in which children could practise spatial skills and knowledge by applying it in a creative way. Origami provides a particularly interesting medium to explore these questions as it has previously been used successfully to train psychometrically assessed spatial skills. This paper details a 'research through design' case study of the development of a theoretically informed origami workshop and its implementation in a makerspace during an after-school makerspace programme. The origami workshop and its pedagogical qualities are described and the implementation of the origami workshop in an after-school makerspace is analysed in light of spatial literacy. These findings are discussed and contextualised with insights from the literature. Finally, several recommendations for further research on spatial literacy for primary school age children, specifically in the context of maker education, are made.

Keywords

Spatial skills, spatial literacy, maker education, origami, STEM learning

Introduction

The Importance of Spatial Skills

Spatial thinking is an umbrella term for a set of abilities and skills that are the product of a complex interplay of sensory, cognitive, and motor processes, which are pervasive throughout our everyday lives (Maresch & Sorby, 2021). As a consequence, spatial thinking is not like a subject onto itself, but rather an important skill across myriad disciplines, and it is a particularly essential component of success in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Wai et al., 2009). Most of the literature on spatial thinking, particularly that showing its relevance to education, is characterised by use of the psychometric construct of spatial ability. Spatial ability is defined as the ability to manipulate and transform mental representations of objects in space. Myriad studies have highlighted the positive effect of training interventions on children's (Hawes et al., 2017; Lowrie et al., 2017) and adults' (Sorby,

2009) performance on psychometric tests. However, there is a significant gap between this body of literature and educational practice (Hawes et al., 2017). For example, training studies, often written from a developmental psychology perspective, rarely consider pedagogy explicitly (Adams et al., 2022). Therefore, spatial literacy is a crucial addition to the literature, particularly from an educational perspective, although it has only received a limited amount of attention in the literature. The authors of the 'Learning to Think Spatially' report describe spatial literacy as *'constituting proficiency in terms of spatial knowledge, spatial ways of thinking and acting, and spatial capabilities'* (National Academies Press (U.S.), 2006, p. 18). Since the report, spatial literacy has been conceptualised as an amalgam of skills in three overlapping domains – visualisation, reasoning, and communication (Lane et al., 2019). Conceptualising spatial thinking and its associated skills as a form of literacy holds a normative implication, but the norms for what one should be able to do with and know about space, representation, and reasoning remain unclear, particularly regarding what is required from children for them to successfully partake in STEM-related learning.

Exploring spatial literacy through origami in maker education

This paper details a case study that describes the design and analyses the implementation of an origami maker workshop in such a makerspace of the *Openbare Bibliotheek Amsterdam* (OBA) [translation: Amsterdam Public Library], the public library of Amsterdam in the Netherlands, in early 2023. Within museums and libraries, across Europe, South-East Asia, and the United States, makerspaces have been established where supervised and structured educational activities are offered (Bevan, 2017; Peppler et al., 2016). Generally, in these makerspaces, maker educators aim to provide primary and secondary school aged children of diverse demographics with educational programmes change in topic from week to week or over longer periods (Bevan, 2017; DiGiacomo & Gutiérrez, 2016). In maker education activities, children learn in rich design-based learning settings through a process that emphasises tinkering, designing, and building (Schad & Jones, 2020). Making activities might involve crafts such as sewing and woodworking, and often make use of (digital) technologies for manufacturing and design such as laser cutters, 3D printers, CNC machines, and microcontrollers (Martin, 2015). In general, maker education and the process of learning in makerspaces differs from classroom education in many ways, emphasising a creative and integrated process of making that involves the use of technology, collaboration, and the sharing of knowledge and skills (Pijls et al., 2022).

Maker education is often framed as a way to improve motivation and learning in specific content areas (Schad & Jones, 2020) and to instil a positive attitude towards STEM-disciplines that helps participants to realise that they too can engage in scientific endeavours (Blikstein, 2013). Furthermore, Zhu et al. (2023) conclude from an extensive analysis of the literature that spatially complex STEM problems provide a context in which children can effectively practise their spatial skills. Maker education could thus be a powerful medium for developing spatial literacy by providing children with spatially complex STEM activities to practice their spatial skills. The primary school age children (usually 8-12 years old) who participate in the after-school programmes are at a stage of their school careers in which they are faced with important choices regarding their future (educational) careers and consequently, they would greatly benefit from becoming spatially literate (Hawes et al., 2022). Origami – the Japanese name for the art of folding paper into figures – provides an interesting medium to address elements of spatial literacy through maker education, as several studies have shown the positive effects of origami activities on measures of spatial thinking (Boakes, 2009; Cakmak et al., 2014; Serrano Anazco & Zurn-Birkhimer, 2020). In an earlier conference paper, the development of this origami workshop and its implementation in the context of an after-school activity in a makerspace were detailed (Westerhof, O'Kane & Duffy, 2023). In this paper, the implementation of the workshop is analysed in light of spatial literacy and these findings discussed and contextualised within the literature on spatial literacy, discussing how spatial literacy may be best conceptualised, particularly for primary school age children within integrated STEM-settings such as maker education.

Literature review

Individual development of spatial thinking

The greatest developments in individual spatial thinking skills occur from about age 3-15 years, with intrinsic and extrinsic spatial thinking skills developing at different stages of childhood (Maresch & Sorby, 2021). Spatial thinking skills relating to *intrinsic* transformations, involve changing the rotation and orientation of objects, scaling objects, cutting or folding etc., and those relating to *extrinsic* transformations, involve imagining and visualising objects from another perspective as an observer and moving in relation to other objects (Newcombe & Frick, 2010). Intrinsic skills most rapidly develop at around 6-8 years of age, whereas extrinsic skills show the greatest development between ages 8-10 (Hodgkiss et al., 2021). Furthermore, it is crucial for children to extensively manipulate objects in space e.g., by creating three-dimensional representations of ideas to learn to visualise and reason about spatial concepts (Yang et al., 2020). This is of particular relevance to a cohort of children who have received much of their education online due to the COVID-19 pandemic (Lane & Sorby, 2022). Spatial thinking skills keep developing considerably until about 14 years of age, when the natural development has mostly completed, but spatial thinking skills remain malleable in adulthood (Maresch & Sorby, 2021). However, there is a significant gap in translating the insights from the educational and cognitive literature into pedagogy (Bufasi et al., 2024). For example, education for spatial thinking is often restricted by the fact that the psychometric factors of spatial ability are overemphasised in interventions (Bower & Liben, 2021). This is problematic, as the psychometric construct of spatial ability is far from comprehensive with regards to the cognitive processes used by STEM experts (Atit et al., 2020), and these processes are only part of what makes up spatial thinking in practice.

Spatial Literacy

What one needs to know and be able to do in relation to spatial thinking has been conceptualised as spatial literacy (National Academies Press (U.S.), 2006). Literacy can perhaps best be conceptualised as a state in which one has attained a certain level of knowledge and skills and can apply them when appropriate. As Grossner & Janelle (2014) explain, although not everyone becomes an accomplished writer, most people can become proficient enough in reading and writing to participate in society in a meaningful and fulfilling way, which is no different with regard to spatial literacy. In practical terms, spatial thinking is perhaps best understood operationally – as an amalgamation of three elements: concepts of space, tools of representation, and processes of reasoning (National Academies Press (U.S.), 2006). Several studies have further developed the concept of spatial literacy over the past decades. An important contribution can be found in the work of Moore-Russo et al. (2013), who argue that to be spatially literate, one must be able to: (1) visualise spatial objects, (2) reason about properties of and relationships between spatial objects, and (3) send and receive communication about spatial objects and relationships. The process of visualising a spatial object can involve an object that is physically present, allowing one to manipulate the object and to assess its properties from different perspectives, while it can also involve the same processes with no object present at all, with the processes purely taking part in 'the mind's eye', spatial reasoning involves manipulating this internal representation of an object to visualise changes to the object or analyse it, and the communication domain relates to exchange of information about these through e.g., sketches, computer models, physical models, or gestures (Lane & Sorby, 2022).

A lot of skills involving spatial thinking involve knowledge that is used to structure the data and sensory information we get into relevant understandings of spatial phenomena. Many of these spatial concepts are important or inherently tied to a particular discipline, which involve complex, conceptual structures of how space is described and explained within it, as illustrated by the striking accounts of spatial thinking in fields ranging from geology to astronomy in the 'Learning to Think Spatially' report (National Academies Press (U.S.), 2006). However, one does not need to master all the specialised spatial approaches that expert surgeons, geologists, architects or mechanical engineers need to become spatially literate. What is pervasive throughout STEM disciplines is referred to by Newcombe (2018) as 'spatialisation' – the use of symbol systems to think and reason about space, for example spatial language, gesture, maps, and diagrams. Although these are often discipline-specific, they can be tied together by their use of the universal properties of space and spatial data such as symmetry, reflection, orientation, and rotation, dimensionality, continuity, and proximity and separation (National Academies Press (U.S.), 2006). These concepts, and the ability to reason with and apply them, can be seen as the universal and fundamental building blocks of spatial thinking in many disciplines, hence they are required knowledge that can be seen as an integral part of spatial literacy (Grossner & Janelle, 2014). In addition to the three domains of spatial skills that together form spatial literacy, there is also a domain of spatial knowledge – a familiarity with a diverse set of concepts – which informs the extent to which the spatial skills in the three previously mentioned domains can be applied. However, the norms and structure of the knowledge and skills that make someone spatially literate are poorly defined. Consequently, it remains unclear what knowledge and skills pedagogical interventions should help students to attain spatial literacy and how this can best be facilitated.

Spatial thinking in origami

The literature on pedagogy for spatial literacy is rather limited, but recent work points to elements such as constructivist pedagogy and utilising hands-on materials like tangrams and blocks as effective approaches to training spatial skills (Bufasi et al., 2024). Further, origami is well-studied in relation to training spatial skills, making it a promising medium to explore which spatial skills and knowledge are pertinent to origami, how those relate to a spatial literacy within after-school maker activities, and how they can be scaffolded. A 2014 study from Turkey reports a statistically significant effect of the origami-based instruction on the spatial visualisation (η^2=.10) and spatial orientation (η^2=.29) scores of 9–12-year-old students (Cakmak et al., 2014). Fujiki & Nishihara (2023) found that the scores on the Paper Folding Test and Surface Development Test were significantly correlated to self-reported ability of individuals to perform origami from instructions (Fujiki & Nishihara, 2023). These tests are measures of intrinsic spatial thinking skills, for which an important qualitative, empirically confirmed, distinction can be made between those relating to 'rigid transformations' and 'non-rigid transformations' (Harris et al., 2013). Harris et al. (2013) found that the ability to predict non-rigid transformation, e.g., how shapes change when a piece of paper is folded, emerges in children of about 5.5 years old. Furthermore, the effects of origami training on elementary school age children are not limited to increases in the visualisation domain of spatial literacy, but also effectuates improvements in engagement and motivation (Cakmak et al., 2014; Taylor & Hutton, 2013). Some studies find a particularly strong increase in engagement from girls, which may make origami a good medium to help close the gender-based performance differences observed on some tests of spatial ability (Taylor & Hutton, 2013). Furthermore, because of the rich spatial vocabulary and concepts used within origami (Taylor & Tenbrink, 2013), it could also provide a valuable medium for children to familiarise themselves with spatial concepts. Because of the rich potential of origami as a pedagogical medium to develop spatial skills in diverse ways, it is an opportune medium to explore how it relates to the larger content and structure of spatial literacy for primary school age children.

Making pedagogy for spatial literacy with origami

One of the fundamental pedagogical approaches in maker education is referred to as 'tinkering', through which children exploratorily practise skills and construct an understanding of what they work with (Resnick & Rosenbaum, 2013). Whereas some activities have a strong emphasis on interest-driven and play-based exploration with tools to facilitate personalised constructive, explorative and collaborative learning (Hsu et al., 2017; Martin, 2015), other activities provide learners with concrete goals, tools, and steps towards realising those goals, with creative freedom in certain aspects of the project (Bevan, 2017). Particularly activities that require technical skills or that are under time constraints are often planned and pre-structured by educators to scaffold children's learning (Blikstein, 2018). Moreover, as Pijls et al. (2023) note, the role of educators is crucial in supporting children to gain confidence in their abilities, to overcome their anxieties, and to embrace times of frustration. This crucial role for maker educators extends to other elements such as mitigating gender-based stereotypes and associations with materials and tools that could affect both participation and learning in maker activities (Bevan, 2017). However, there is a strong need for more detailed analyses of what learning can occur in educational makerspace settings (Bevan et al., 2015). Similarly, Pijls et al. (2022) conclude that informal learning settings such as library makerspaces would benefit from integrating insights from the cognitive and learning sciences to help to show how informal learning settings such as makerspaces allow for unique learning opportunities.

Research Questions

In summary, although it has become clear why it is necessary to support the development of spatial thinking, the 'what' remains rather vague – it is unclear what the structure of spatial literacy for primary school age children in maker education is, which skills and knowledge need to be developed and how pedagogy for spatial literacy may look. This leads to the following research questions:

1. What does a maker education workshop look like, in which primary school age children can learn, tinker with, and creatively apply origami techniques?
2. How is spatial literacy relevant for primary school age participants while they participate in this origami workshop in the context of an after-school makerspace?

Methodology

Procedure

An 'intensive' case study approach (Danermark et al., 2019) was taken, to explore, through an in-depth analysis of several sources of qualitative data, which spatial skills and knowledge manifest in a specific activity and how they are relevant to the larger structure of spatial literacy. The case study is rooted in a 'research through design' process, which can be characterised as when design activities play a formative role in the generation of knowledge, for example reframing a design problem and iteratively developing and evaluating prototypes to address the complex situation in which the problem occurs (Stappers & Giaccardi, 2017). As Stappers and Giaccardi (2017) explain, such a design artifact can create the possibility for people to engage in interactions that were not possible before the design came into existence, making novel interactions observable. The research through design process and the design artifact themselves are thus part of the core epistemological strategy through which the researcher comes to new insights. As part of this research through design process, the first author engaged in ethnographic data collection methods. First, he observed several workshops from the regular after-school programme in the maker space and then discussed the format and the didactic approaches taken by the coaches in those workshops to aid the iterative process of developing the origami workshop. These insights were then used to design the workshop detailed as the first part of the results. Next, the implementation of the origami workshop during an after-school programme in a makerspace at the public library of Amsterdam was investigated. Observational data were collected through observation notes and photographs, and after the workshop was done, the first author wrote up a narrative description of the workshop. Finally, a week after the workshop, an informal debriefing with the coaches took place to reflect on and discuss the implementation and structure of the workshop, during which the first author took notes. These data were then analysed by the first author.

Participants

The workshop was attended by 12 children of primary school age, six girls and eight boys, and two boys in the first year of secondary school. The origami workshop replaced the workshop in the regular programme of after-school workshops. The first author acted as workshop host instead of the two makerspace coaches, who instead took on dynamic roles, working on origami themselves, supporting the child participants in their origami folding, and helping the first author to host the workshop as they saw fit.

Results

Design of the origami maker workshop

A two hour-long origami workshop was designed that lets children tinker with basic origami techniques and skills, which they then creatively apply to come up with original origami designs. The first half of the workshop started with a brief plenary introduction to origami instructions and folding. Origami instructions show the linear sequence of transformations the paper needs to go through to recreate a final design, illustrated through diagrams and symbols in standardised in the Yoshizawa-Harbin-Randlett system (Lang, 2012). The participants then receive step by step instructions for several simple origami models on a handout. For about 45 minutes, the children explore how to fold classic origami designs using instructions on a handout (Figure 1), while they discuss and help each other. This is followed by a plenary discussion in which the children share their experiences of making origami.

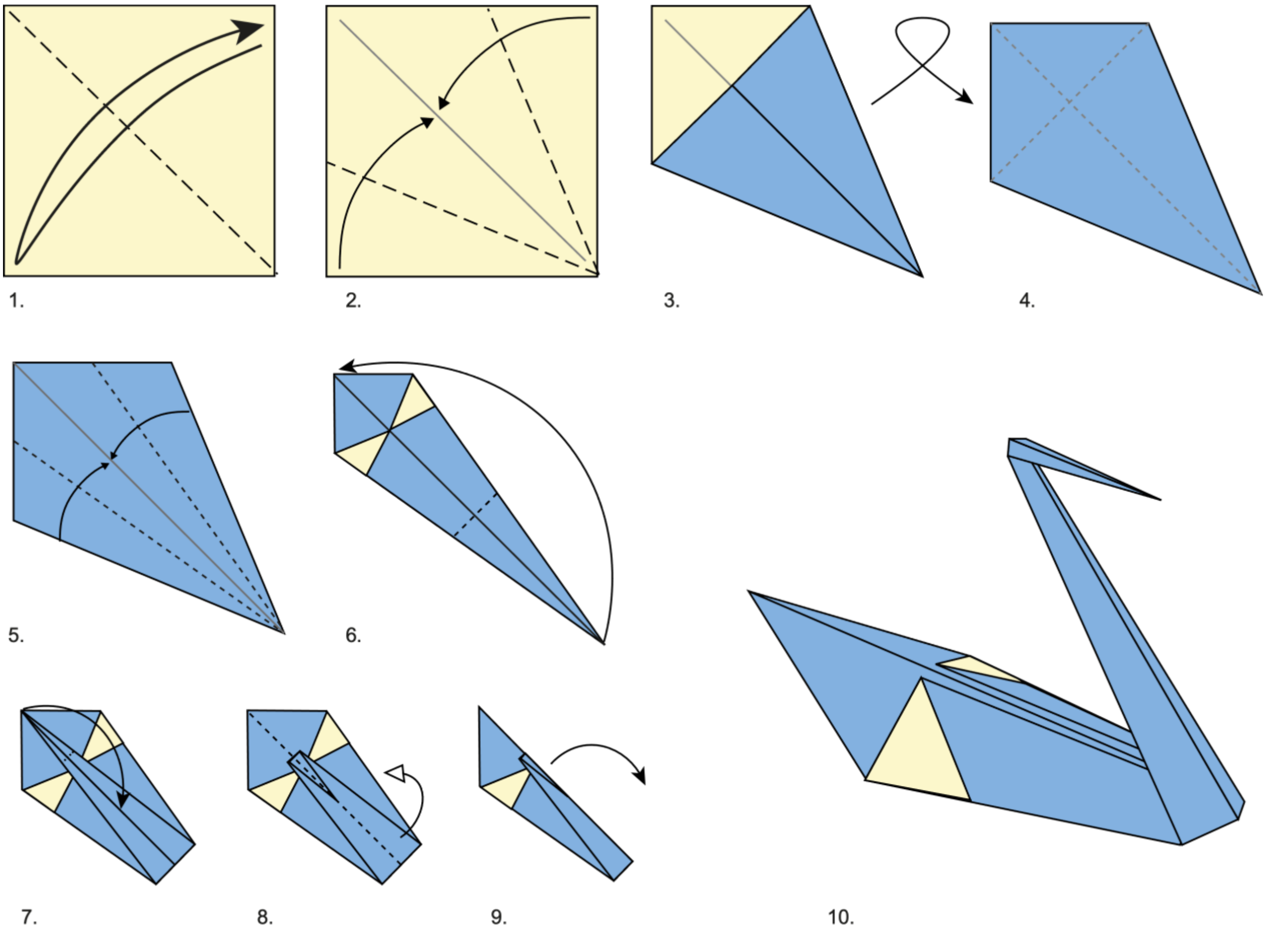

Figure 1. Origami instructions for the swan model

The second half of the workshop was informed by Chapter 4 of the book 'Origami Design Secrets' by Robert Lang (2012), and a course on YouTube by Brandon Wong (2022) based on the book by Lang. The children are introduced to three 'classic' origami bases (Lang, 2012) – the fish, bird, and kite – and shown several different origami designs based on each (Figure 2). These geometric forms can resemble an abstracted version of desired subject that has the same general shape or number of flaps (Lang, 2012). A flap is a region of paper that can be manipulated relatively independently from the rest of the model, which can be folded to represent, for example, an appendage.

To recreate an animal, one can try to find a base of which the number of flaps corresponds with the number of appendages of that animal. For example, a fish base consists of two large flaps, which can be used to shape the head and tail, and two small flaps, which can represent the pectoral fins. The children are then tasked to design their own (fantasy) animal using one of the bases and the techniques learned in the first half of the workshop. This process is described as 'doodling' (Robinson, 2004, p. 38) – analogous to tinkering – where folding techniques are exploratorily and creatively applied to come to new ideas.

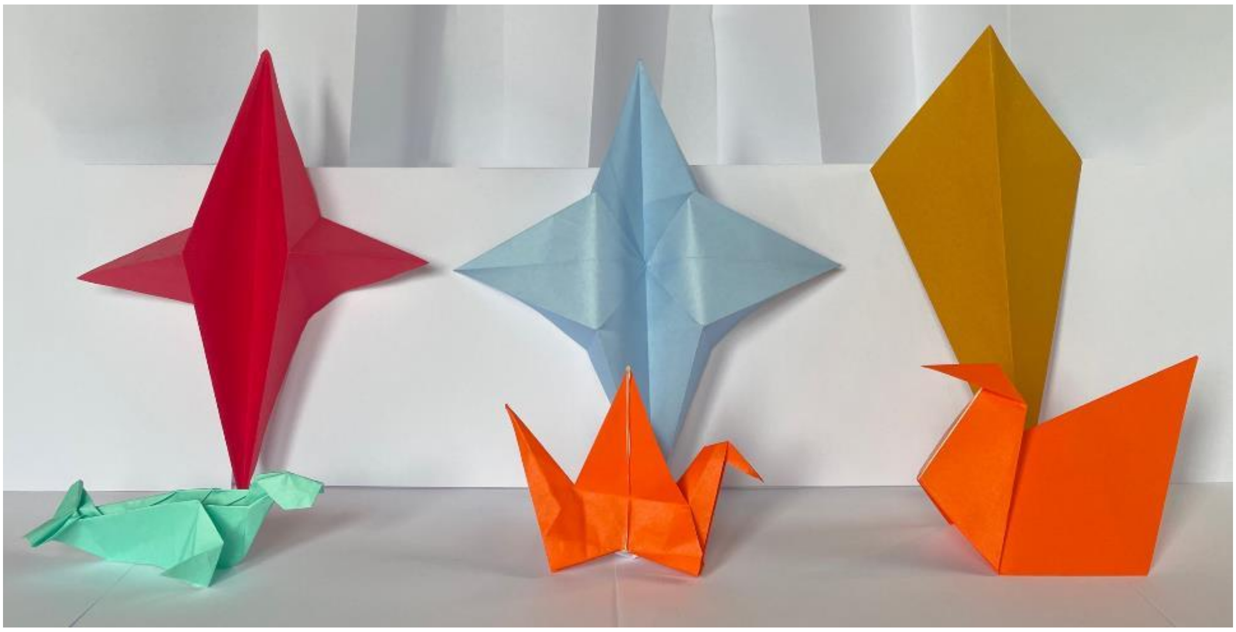

Figure 2. From left to right: a fish, bird, and kite base with examples of designs based on each

Implementation of the origami maker workshop

Individual differences in spatial literacy

In the first half of the workshop, all children engaged with the origami instructions, but their degree of success in following the origami instructions varied greatly. This is illustrated by how many children continuously called upon the researcher for help while they explored the origami instructions, as shown for example in Figure 3. Some of the children waited for the facilitator to explain each step to them, while a small number of children seemed to give up entirely and asked if they could do something on the computer instead. This was contrasted by the two boys who had indicated at the start that they would prefer to work on their own projects in the makerspace, who independently and very quickly finished their swans after the plenary introduction. They then opened laptops to work on their own projects, which involved part 3D-modelling in TinkerCAD and a more significant part playing video games. It thus became apparent that some children were able to fold independently and successfully while others required extensive assistance, but also that individuals reacted to their success or struggle in folding the origami models from the instructions in qualitatively different ways. For example, when during the second half of the workshop the researcher explained how classic origami bases can be used to design novel origami, the children were asked to start the process of doodling to come up with an original design. However, this task appeared to be too daunting, as most children, except one or two, started doing other things in the makerspace.

Figure 3. Three children folding the swan model.

Video circumvents the need for diagrams

In response to the difficulties that were faced by the children while they tried to come up with novel designs, one of the makerspace coaches looked up an instructional video for making an origami elephant, which she displayed on the large TV-screen in the makerspace. The video helped in regaining the attention of many of the children, particularly the children who had previously struggled with the instructions. The children all followed the steps in the video, which was paused periodically by the coach so all children could catch up. Most children seemed to find it much easier to follow the first-person perspective instructions in the video than translating 2D diagrammatic instructions in the handouts into actions. However, instead of trying to apply their newly practised techniques to create a novel origami design, the children were again recreating an existing model of an elephant (Figure 4). However, now they did not have to decipher diagrammatic instructions.

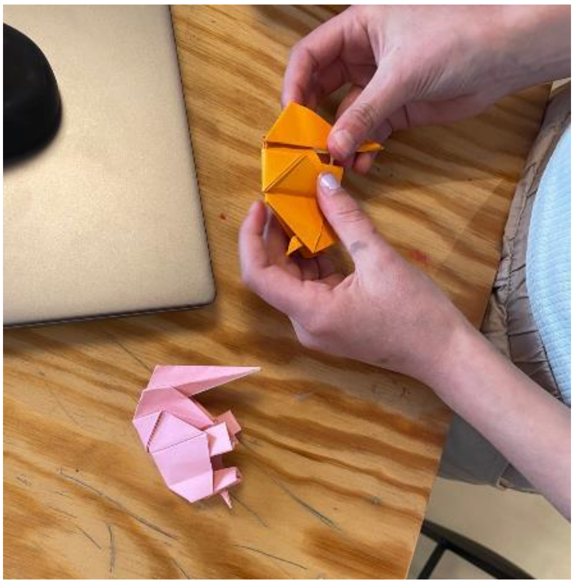

Figure 4. Folding elephants from a video

Spatial creativity comes in different shapes and sizes

While the children were following the instructions for folding the elephant, two of the children noticed independently of each other that this elephant origami was designed from the bird base, which they had folded earlier in the workshop. While folding the elephant from the video, a boy thought that an intermediate step of the elephant looked like a dinosaur, which he preferred over the elephant (Figure 5). This boy had previously independently recreated one of the examples designed from the fish base by the facilitator, showing an ability to harness his spatial thinking skills creatively and analytically.

Figure 5. A boy doodling to come to a new design.

In the first half, two girls had decided that they would fold the swan in all available colours. When asked by the researcher if they would also like to try folding the crane, a more challenging model, they responded no, and both girls spent a significant period of the workshop folding the swan model from all the available colours (Figure 6). In contrast to the previously mentioned boy, these girls perhaps did not engage with a spatially challenging task after the initial challenge of deciphering the instructions, but they did show a playful commitment to making a creative series. Before they left, one of the girls who made a rainbow of swans and the boy who had recreated one of the examples both asked if they could take home the handout and a few sheets of origami paper to continue making origamis at home. As the girl left, she said: “I love origami!”. Although in this case the activity failed to engage the girls in a more spatially challenging task, it does show an important benefit of open-ended creative tasks – allowing each child to find an angle to the activity that is personally meaningful and fulfilling, setting them up for later independent learning.

Figure 6. A participant displaying her creations.

Discussion

Spatial literacy: spatial skills, knowledge – and beliefs

Previous research on the effects of origami instruction in relation to spatial thinking has not only shown the positive effects on measures of spatial ability, but also has pointed to the positive effects on the motivation of girls. Similarly, in the limited sample we observed in this specific case, most of the girls actively engaged in origami. Potentially, origami could be a valuable medium for engaging children in spatial skills. This is particularly pertinent because there is a large body of research on the effects of stereotypes and self-beliefs on spatial thinking, which points towards the strong negative effects of gender-based stereotypes and self-concepts such as spatial anxiety, which negatively influence how children engage with spatial problems (Burte et al., 2020; Lennon-Maslin et al., 2023). An important question is whether the children who did not engage with the 'spatially challenging' elements of the workshop, such as the girls who spent most of the workshop recreating the same model, would benefit from more explicit spatial training. However, further research is necessary to investigate individual levels of spatial literacy in relation to how the children engage with the workshop to be able to make any further conclusions.

Further, this also raises the question how self-beliefs should be conceptualised in relation to whether an individual can be considered 'spatially literate'. In the 'Learning to Think Spatially' report (National Academies Press (U.S.), 2006), one of the characteristics of a spatially literate individual is considered to be having the habit of mind to think spatially – knowing where, when, how, and why to think spatially. Therefore, a prerequisite is that an individual has a healthy level of self-efficacy regarding their spatial skills and knowledge, as only then will they engage with and practise the application of those skills when the situation calls for it. This begs the question whether self-beliefs should be considered an integral part of the conceptualisation of spatial literacy, as from an educational standpoint they are important elements to be addressed.

Diagrams: a barrier or enabler to understanding space?

One of the main observations that informed the analysis related to the use of an instructional video during the workshop. This video showed a first-person perspective of two hands folding an origami elephant, and many of the children who had stopped working on anything origami-related were drawn back into the workshop again. Within many STEM and non-STEM disciplines, diagrams play a crucial role but the skills and knowledge that are required to engage them are often neglected (National Academies Press (U.S.), 2006). Diagrams are used to structure spatial information, but often do not directly show function or behaviour, which need to be inferred (Heiser & Tversky, 2002). This is often scaffolded through 'extra-pictorial devices' such as lines and arrows to convey e.g., transformations that need to be inferred (Heiser & Tversky, 2002) – similar to how the origami instructions in this activity were illustrated in the Yoshizawa-Harbin-Randlett system (Lang, 2012). In the case of the origami workshop, the reason many children were drawn back in by the video might have been because it was easier for them to follow a video which shows the correct procedure from the same perspective as they themselves view their hands, circumventing the need to interpret diagrams. Folding origami from diagrammatic instructions requires a variety of spatial skills during the translation of diagrammatic instructions into transformations of the paper, which involves a process of visualising and reversing, rotating, turning over and inverting models (Taylor & Tenbrink, 2013). Initial individual levels in spatial skill can have a strong influence on whether students correctly interpret diagrams (Kozhevnikov et al., 2002). For example, spatial thinking plays a decisive role in accurate problem representation in mathematics (Duffy et al., 2020). Structured practice with spatial diagrams – involving spatial representations and transformation of spatial information – could facilitate significant benefits with regards to participants' spatial literacy (National Academies Press (U.S.), 2006). This is one of the crucial things that the maker workshop can help teach, particularly when actively scaffolded by educators. Therefore, the video might have appeared to the educator as an appropriate didactic approach to regain the children's attention, but in the light of spatial literacy, may have taken away the opportunity to practise valuable skills related to interpreting diagrams.

Rubrics: making spatial literacy assessable

In this specific case study, it was explored how maker education provides a valuable context in which children can develop a wide range of spatial skills in a context where educators can help to structure these skills. It became apparent that knowledge of spatial concepts is a requirement for engaging with spatial skills, as these concepts are integral to how the spatial information is structured. In this workshop, spatial concepts such as symmetry, reflections, and fractions were integral parts of the origami design task. Furthermore, origami provides the opportunity to engage with rich spatial language (Taylor & Hutton, 2013), which is well known to play an important role in developing children's spatial thinking (Newcombe, 2018). In addition, self-beliefs regarding spatial thinking may play a crucial in how children (are able to) partake in activities that require spatial skills. For children to attain spatial literacy, educators need to understand how they can support children's spatial skills, knowledge, and self-concept through the wide variety of spatial challenges that emerge in the context of maker education activities.

That raises the crucial question of what the norms are for spatial literacy for primary school age children in relation to those skills. Another apparent challenge to defining spatial literacy relates to the extent to which student learning of spatial knowledge and spatial skills relate to a specific area of expertise and thus how those skills and that knowledge can be transferred to another area of expertise or be applied in general. Secondly, for educators to support children in their development of those skills, it is crucial to have pedagogical strategies and tools such as rubrics to help them to assess individual children's development on those norms. Perhaps it is impossible to define a comprehensive list of spatial skills that are relevant, but future research could define the spatial skills present in maker education to be able to define which spatial skills and knowledge are crucial within maker education settings and how educators can identify their use and potential extent among participants to better support their development. Furthermore, such rubrics would allow for measuring the impact of an intervention such as the one described here, to further elucidate and potentially quantify the impact. Furthermore, this would allow for the effect on such scales to be measured based on engagement in such a workshop, allowing for research designs with larger generalisability. Because of the crucial role the maker educators have in providing adequate scaffolding and support for children to develop their spatial literacy, further research could benefit from involving the views of experienced maker educators in relation to what they consider relevant spatial skills and how children apply these, which can help to develop a better-defined understanding of spatial literacy within the context of maker education activities.

Conclusion

This case study detailed the design and implementation of an origami workshop, in which primary school age participants learn to creatively apply origami techniques, which was analysed through the lens of spatial literacy. Observations from the study indicate that a well-designed and implemented workshop can be used to elicit a variety of spatial practices, providing a valuable medium to investigate how activities and educators may support the development of spatial literacy within makerspaces. Spatial literacy is an amalgam of skills and knowledge that is influenced by self-beliefs. Diagrams are a spatial tool that can elicit spatial skills but may work as a barrier for students who are not spatially literate. Therefore, it is crucial to understand which skills and knowledge are crucial to attaining 'domain-general spatial literacy'. Through a future study, the making process of several children could be analysed for the diverse forms of spatial practices that are required in diverse maker education activities and how educators support these practices within their makerspaces. This would provide a valuable step towards a better understanding of what should be considered spatial literacy for primary school age children, how primary school age children could develop spatial skills during design-based maker activities and how educators can support them in harnessing this set of crucial skills while working on projects that are important and engaging to them.

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29.2

Understanding students' learning of technology through interaction supported by virtual reality

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Abstract
Given the profound influence that technology has on society, shaping our behaviours, conversations, and decisions, it is essential to understand its development and nature. Obtaining a complete understanding of technology requires us to explore both the nature of technology and its historical aspects. This study examines how using supportive images in a virtual reality (VR) learning environment, combined with verbal interactions, supports students aged eight and nine in developing an understanding of the nature of technology. Data were collected during an ordinary technology teaching activity and the analysis highlighted that these students, through interactions and VR images, demonstrated knowledge of all dimensions of technology, as described by DiGironimo (2011). The analysis of the findings indicated that the students' knowledge could be categorized, but there seemed to be more complexity in their utterances than DiGironimo's model could capture. Additionally, I employed a discursive analysis to achieve a deeper comprehension of the students' perceptions of the history of technology. Here, the findings indicate that VR images can promote students' interaction related to the history of technology, which often leads to exploratory conversations. The findings have the potential to support teachers in planning and conducting technology activities in primary schools, where images and verbal interactions could provide decisive support for developing an understanding of the nature of technology, especially the historical dimension of technology.

Key Words
DiGironimo, Discursive moves, Historical dimension of Technology Primary students, Technology Education, Virtual reality images, Virtual reality.

Introduction
It is essential to understand how technology develops and what it is, not only because most of our modern society depends on it but also because technology employs a significant presence and pressure in various aspects of our daily lives, shaping our behaviours, interactions, choices and even our thought processes (Arthur, 2009). Society and technology are determined and emerge in an intertwined sociotechnical activity (Bijker, 1999). Therefore, knowledge of technology is too important to be left to a few specialists (Arthur, 2009). In this regard, the Swedish curriculum states that teaching technology should enable students to think about technological change and historical perspectives on the development of technology (Hallström, 2023; Skolverket, 2022).

Learning about technology's historical failures and successes could explain how an emerging technological society is shaped (cf. Condoor, 2004; Read & Alexander, 2019). Latour (1990) argued that to be able to achieve an understanding of technological systems (such as infrastructures) and incorporate new narratives about them, one could follow the development of an invention. Technology and society are interrelated regarding the development of each other (Franklin, 1999).

Eliasson et al. (2023b) stated that the historical dimension of technology, as part of the nature of technology, is important to be able to understand new emerging technologies and their advances and that technology is a central part of civilisation (see also Liou, 2015). Therefore, becoming technologically literate involves knowledge in and about older and newer technology and is thus about becoming historically educated in technology to be prepared for readiness for action in the future (Hallström, 2023). Consequently, if the historical dimension of technology is not included in the general understanding of technology, it will not be easy to develop knowledge and understanding of the emerging modern technology's impact on society, humans and the environment (cf. DiGironimo, 2011; Eliasson et al., 2023b; Liou, 2015). Further, excluding the historical dimension makes it difficult to understand contemporary technology issues and their effect on society and humans (Eliasson et al., 2023b). Therefore, teaching and learning about the history of technology is central to technology education.

The present study focuses on students' interactions concerning mundane technology. To get close to the students' thoughts on the history of technology, a *virtual reality learning environment* (VRLE) was designed. The VRLE includes communicative situations in the classroom where *virtual reality* (VR) images support the students' verbal interactions. Here, VRLE incorporates an environment where the students can engage in exchanging ideas and provide conditions to interact on technology. Through the teacher's questions and interactions with fellow students, they may jointly develop an understanding of mundane technology, both contemporary and historical.

Less is known about the impact of VR images in promoting young students' developing knowledge of the nature of technology. This study examines student interactions and delves into how VR environments support student discussions. By closely examining these interactions within VR learning environments, the study reveals the potential that VR environments hold in enriching students' understanding of the nature of technology. Therefore, the present study examines how interactions incorporating image-based virtual reality experiences can support primary students in demonstrating knowledge of the history of technology.

Aim and research questions

The study aims to investigate primary students' developing knowledge of the nature of technology. An additional aim is to examine how supportive images in a virtual reality learning environment support students' verbal interaction.

These aims led to the following research questions:

- In what ways do primary students demonstrate knowledge of the nature of technology?
- In what ways do images in a virtual reality facilitate small group interactions related to the history of technology?

To give the students opportunities to develop knowledge of the history of technology, it was achievable to let them partake in a VR experience where two parallel timelines were displayed.

Theoretical background

Students’ development of technological knowledge

DiGironimo (2011) constructed a conceptual framework (see Figure 1) including five dimensions that represent the nature of technology. Each side represents different perspectives of technology, labelled as *artefacts* (including products of technological innovation and educational technology tools), *a human practice* (the role humans play in the production, maintenance and use of technology), and *a creation process* (the technological design process and methods of technology). These sides cannot exist without each other, indicating that one cannot engage in technology as a human practice without engaging in the dimensions of technology as artefacts and technology as a creation process. *The history of technology*, technology as an essential part of human history, forms the base of the prism, while the way the prism stands up represents the technology evolving out of its history. The purpose of technology, *The Current Role of Technology in Society,* is placed at the top of the prism to show time in a vertical direction and that the prism will never be fully complete.

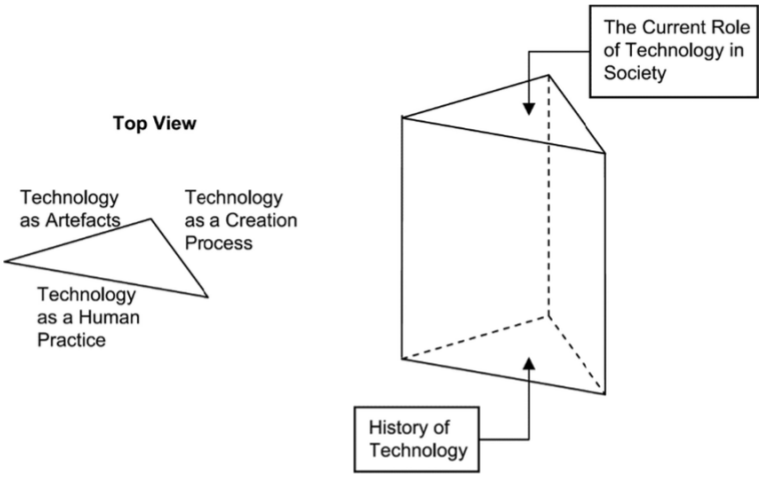

Figure 1. The nature of technology (DiGironimo, 2011)

The historical dimension of technology in the framework (DiGironimo, 2011) can be used in technology education. It is a way of showing that technology has developed throughout history and thereby gives students opportunities to develop widened knowledge about technology (cf. Eliasson et al., 2023a).

The history of technology is not a clear linear development (Mitcham, 1994), and the making of artefacts is not always a simple gathering of technological knowledge. It is not only social needs and values that are central to the development of artefacts but also philosophical ideas. This indicates that developing and manufacturing artefacts historically is not a simple process (Mitcham, 1994). In addition, de Vries (2016) presented a distinction between experience-based technology and micro-technologies. Here, experience-based technologies are referred to as technology developed through human history, and micro-technologies are referred to as technologies in which essential parts are microscopic technology, such as microchip technology.

In a study on technology teaching in preschool, Eliasson et al. (2023a) explored how technology activities are carried out and what knowledge is made accessible for the students to learn through the interaction between the participants. The results indicate that technological knowledge was established related to four of DiGironimo's (2011) five dimensions of technology. However, none of the students related to the historical dimension of technology. This is in line with an exploratory study conducted on middle-aged students (Grades 6, 7 and 8), aiming to develop a tool for analysing student conceptions of the nature of technology (DiGironimo, 2011). The students' answers to the survey were related to the conceptual framework (see Figure 1) developed by DiGironimo (2011). The results indicate that the students lack knowledge of the dimension history of technology.

Lind (2023) discussed how students perceive and develop knowledge of technological artefacts in their nearby environment. Based on the students' prior conception of technology as contemporary technological artefacts, the findings indicate that students (aged eight and nine) are capable of advancing a nuanced view of technological artefacts, for example, developing knowledge that technology could be considered as experience-based technologies (cf. de Vries, 2016) and not just contemporary artefacts functioning with electricity.

Research on virtual reality in education

VR can support students in moving outside the classroom, thereby taking advantage of opportunities to learn about things available in out-of-school settings and extending learning beyond the classroom (cf. NETP, 2017; Sala & Sala, 2005), which can lead to a deepening understanding, for example, of technology. It is also a way of processing information and making it more comprehensible (Sala & Sala, 2005). Hence, VR enables a teaching and learning environment where the visual plays an important role when the students develop an understanding of concepts (cf. Nooriafshar et al., 2004; Shao-Chen et al., 2020; Song & Li, 2018). This is a growing field of educational research that examines opportunities and obstacles in the use of VR in teaching and learning.

Petersen et al. (2022) described two features of virtual reality: *interactivity* and *immersion*. Interactivity is the degree to which the student can interact with the virtual environment the students are put in (Steuer, 1992; Mütterlein, 2018) and the freedom the students are given to control the learning experience (Petersen et al., 2022). The students' perceived interactivity could be considered as their possibility to influence the virtual environment interactively when looking at the individual's presumptions and prior knowledge of VR (Mütterlein, 2018). Immersion could be described as the feeling of being caught up in and absorbed by the virtual environment, as well as how the student enjoys the experience (Petersen et al., 2022; McMahan, 2003). Slater (2018) highlighted the concept of presence in VR, which is the illusion of being in the place and perceiving and responding to the object displayed in the VR environment.

Korallo et al. (2012) conducted a study consisting of a virtual environment with three parallel historical timelines presented to 27 undergraduate participants. The purpose was to use a virtual environment, which possibly enabled students to cross-refer while taking active action through a virtual historical environment and thereby remembering information better. The authors suggested that undergraduate participants could use the virtual environment more effectively, as they remembered historical chronology better than when the same material was taught using standard learning materials in the control group (Korallo et al., 2012). Parong and Mayer (2021) asserted that students achieve better learning outcomes through lessons utilising low-end VR equipment, characterized by low immersion and a low sense of presence, a finding supported by Selzer et al. (2019). Here, Foreman et al. (2008) found that primary-aged students answered historical chronological questions more correctly when using successive images on paper than after virtual environment experiences. Consequently, it appears that primary-aged children are slightly disadvantaged compared to older students when using virtual environments to learn historical material, which indicates that the use of paper images can be as good as using virtual environments in history teaching (Foreman et al., 2008). However, Albus et al. (2021) stressed that *signalling* (visual or auditory cues) through directing students' focus and attention (cf. Mayer, 2014) may support and improve students' learning outcomes (Ozcelik et al., 2010) in VR environments, especially when recalling knowledge and making sense of the presented material (Mautone & Mayer, 2001). Here, signalling becomes essential in the teacher's guidance of students' attention and focus on technology in the interactions to improve learning and understanding. The teacher uses signalling when overlay images and arrows to point out a specific perspective of technology, for example, historical dimensions.

Theoretical perspectives

In this study, examining verbal interactions within classroom settings proved essential for gaining an understanding of students' understanding of technology. Verbal classroom interactions between students are essential in technology education, encompassing situations where students are inspired to collaborate and become involved in discussions with fellow students to explore different perspectives on technology (Fox-Turnbull, 2018). By creating situations for interaction containing digital tools, such as VR, in the classroom, students' world of experience can be broadened (Kerckaert et al., 2015; Mercer et al., 2019). In that context, the teacher's use of signalling becomes essential for initiating and perpetuating student discussion. Lind et al. (2024) and Lind et al. (2019) highlighted that visualisations can support students in representing and communicating their understanding and knowledge of technology in classroom interactions. Walldén and Nygård Larsson (2021) emphasized that images can be advantageously chosen to enable students to make connections with their prior knowledge and personal experiences.

Students have varying abilities to articulate concepts as they move between everyday and scientific languages, as well as in their success in formulating subject-specific language (Nygård Larsson & Jakobsson, 2017). The concept of discursive moves describes a linguistic move between everyday discourse and a subject-specific discourse, a movement between the concrete and the abstract, as well as a movement between the specific and the general (Nygård Larsson & Jakobsson, 2017). Mercer and Wegerif (1998) defined exploratory talk as speech where students engage critically and constructively with each other's ideas to reach a joint agreement. Indicating that knowledge and ideas are explicitly debated, students' reasoning is visible, and the talk offers justifications and suggestions. In the exploratory talk, language is essential for successful participation in disciplinary discourses (Mercer & Wegerif, 1998), such as the practice of technology. To explore its impact on disciplinary discourses, discourse analysis was applied. The sociocultural discourse analysis focuses on the significance of language as a tool for teaching and learning, collaborative problem-solving, constructing knowledge and sharing understanding (Mercer, 2004). In an educational setting, discourse analysis refers to the analysis of sequences of talk in a social context, such as a small group of students solving a joint problem; in other words, how language is used and the quality of the interactions are changed during a collective thinking activity (Mercer, 2004).

Bansal (2018) identified three goals that are served by teachers' *discursive moves*. These moves are being used by the teacher to bring coherence and establish a culture of dialogue in the classroom setting. The dialogic discourse (cf. Mortimer & Scott, 2003) has been categorised as foundation, initiation, and perpetuation. Firstly, the foundation moves lay the foundation for rich discussion to occur. Secondly, the initiation move involves stimulating the students' interests and enlightening them with different perspectives. Lastly, the perpetuation move regards the teacher's perpetuating interest in the initiated subject in the dialogues. This involves teachers encouraging rich dialogues supporting students to elaborate on the reason behind their ideas, as well as organising safe opportunities for productive exchanges of ideas and basing the discourse on students' arguments and reasoning (Bansal, 2018).

Nennig et al. (2023) created a framework to analyse discourse from students' perspectives. The framework, Students Interaction Discourse Moves (SIDM), has three levels: *type of interaction*, *primary intent*, and *nature of utterance*. Nennig et al. (2023) emphasized that the first level – the type of interaction – states how students broadly interact with each other, for example, *independent work*, *instructor interaction*, *on-task*, and *unengaged*. The second level – primary intent – states the purpose of the student's interactions and involves discursive moves, such as *concluding*, *initiating*, *commenting*, *questioning*, and *external interaction*. The third level – nature of utterance – characterizes in what ways students engage in a specific discursive move; for example, *agreeing*, *assessing*, *building*, *clarification seeking*, *explanation seeking*, *information processing*, *personal remark*, *presenting a claim*, *repeating*, *rejecting*, and *summarizing*. The framework can be utilised to identify how and when students engage in specific discourse moves, essential to achieve rich descriptions of students' interactions in small groups. Further, it can be used to identify factors that promote interactions where students jointly exchange ideas with each other to develop a joint understanding (Nennig et al., 2023).

Methodological considerations

To enable interactions about the history of technology, images in VR were accessible to support students' move towards a deeper understanding of technology. In this study, the VR images were essential to the interactions. The selected VR images were closely related to a specific content area, such as technological artefacts, containing information and located in an environment students recognise, like a kitchen (see Picture 1). VR allows students to visit environments that are not otherwise available in a classroom, which can enable understanding. In exploring the VR environment, they apply pre-understanding of technology and gain new insights, enhancing their understanding of technology (cf. Hite et al., 2023).

Picture 1. Images relating to the kitchen

The immersive virtual reality learning environment (VRLE) supports active participation, discussion, and collaboration, making learning dynamic and interactive. The students engaged with the VR images and discussed the experience with fellow students to progress through the teacher's instructions and questions (see Figure 2). In that way, the VR image supports a mutual focus for the students in the class. VR can be significant for enabling subject-focused interaction on technology, which can strengthen technology teaching and enhance students' learning (cf. Bansal, 2018). In the study, the students utilised VR images to explore and identify the 19^{th}-century environment and relate this with 21^{st}-century overlay images. The intention of utilising two historical timelines was to create a historical relatedness between interrelated mundane artefacts. This means that the VRLE provides the students with opportunities to collaboratively engage in exchanging ideas to reach a joint understanding of content (cf. Bansal, 2018).

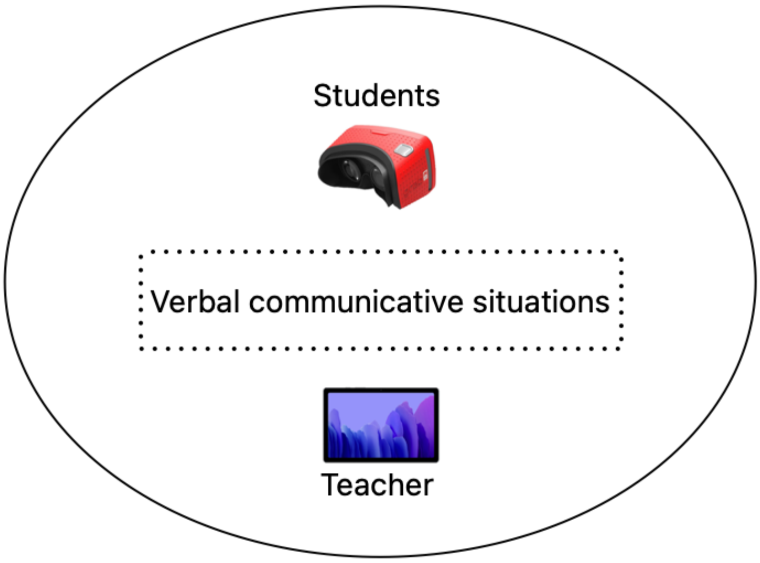

Figure 2. Virtual reality learning environment (VRLE) in this study

In this study, VR refers to hand-held low-immersive VR equipment for smartphones (see Picture 2) that has a low ability to interact with the displayed environment (cf. Juan et al., 2018). The enveloping 360° image can create a sense of temporal immersion (cf. Efstathiou et al., 2018), as the students can interact by moving their heads, thus eliciting a feeling of being present in the chosen historical time (Livatino et al., 2022).

Picture 2. VR technology used in the classroom

The teacher guides the teaching from a tablet and switches images alongside verbal questioning and instructions. Following this, opportunities appear to decide what the students should look at; for example, some points of interest in the enveloping 360° image, such as a pair of shoes. The teacher verbally and by signalling directs the students' attention to a specific artefact to involve it in their interactions (Albus et al., 2021), making it possible to direct the students' attention and coordinate a mutual focus on specific content. In conclusion, the virtual reality learning environment can facilitate and frame teaching (see Figure 2). In addition, VR supports the students in delineating and directing attention to the essential parts that the teaching aims at.

As described earlier, VR is utilised to create immersion and enable the teacher to, through signalling, add and display 2D overlay images to emphazise technological artefacts in the enveloping image. Thus, the distance between the present and the past is shortened, as the enveloping 360° image represents a 19th-century house, and the overlay images are from the 21st century.

Settings and participants

This study was conducted in a multilingual municipal school in the southern part of Sweden and followed ordinary teaching in technology. The class involved 24 students, aged eight and nine, and their teacher. The participating students were familiar with learning activities involving VR. In these, the VR images function as a mutual focus of the student's interactions. The empirical data consisted of one audio and video-documented technology activity (60 minutes) encompassing a VR experience. The audio recordings (using six pieces of equipment) were undertaken while students worked in small groups (2–4 students in each), while the video recording equipment mainly focused on the whole class discussions. By creating communicative situations, the students were given opportunities to develop and deepen their subject-specific language, for example, by using fellow students' statements and using them to demonstrate new knowledge (cf. Mercer et al., 2019). In the present study, a statement means anything that has been verbally uttered by anyone in the group. Therefore, the meaning of the utterance could differ between groups and individuals regarding the students' verbal abilities, such as second-language students. In these situations, working in small groups creates better conditions for facilitating interactions (e.g. Jakobsson & Kouns, 2023).

Earlier research has stated a positive relationship between VRLE and learning outcomes (cf. Korallo et al., 2012), such as making information and concepts comprehensible (cf. Sala & Sala, 2005). Using VR images achieves positive learning outcomes (for example, in technology teaching), regardless of the level of immersion. To investigate these outcomes, a study was conducted in a VRLE in a classroom setting (see Figure 2). The verbal interactions among students, teachers, and VR images were recorded, transcribed, analysed, and discussed concerning previous research.

Ethical approval

Ethical approval was required. Therefore, informed consent from the guardians was collected (Shamoo & Resnick, 2015; Ministry of Education and Research, 2021). In addition, an application for an ethics review was made, with a positive response (Codex, 2022). Ethical aspects were treated according to the current ethical considerations of the Swedish Research Council (2017).

Collecting data

The aim was to investigate how students demonstrate knowledge of technology through verbal interactions supported by images in VR. Therefore, getting close to the student's knowledge and understanding of mundane technology was desirable. The technology content in the activities included finding and discussing technological artefacts in the enveloping 360° VR image. This gave opportunities to answer the research questions.

The audio recording equipment was placed in each group to record the individual students' expressed knowledge of technology. The whole-class discussions were recorded on the video-recording device. The focus of the interactions was directed towards technology. In total, the empirical data encompassed 257 minutes.

To ensure the results were reliable, I spent time in the classroom before data collection to ensure that I affected the learning situations as little as possible. The conclusions are drawn from a solid theoretical foundation based on previous research on students encountering technology in school. The findings are not generalizable, but transfer to similar contexts is possible, although students' various ways of interacting may affect the findings (cf. Tracy, 2010).

Analytic process

Thematic analysis is a reflective method that is useful when investigating various perspectives of participants and identifying similarities and differences (Nowell et al., 2017). The deductive thematic analysis aims first to address the research question of how students demonstrate knowledge of the nature of technology and categorise students' knowledge of technology by utilising DiGironimo's framework, which offers a comprehensive understanding of technology by also emphasizing its historical dimension. This means distinguishing within which dimensions of the framework the students express knowledge. Secondly, the analytic procedure continued with a discursive analysis approach to achieve a deeper understanding of the students' understanding of the history of technology.

All of the collected data were reviewed rigorously, carefully and repeatedly (cf. Cohen et al., 2011; Nowell et al., 2017), and content-related situations during students experiencing technology in a VR environment were selected (257 minutes). The content-related situations consisted of students verbally expressing knowledge of technology, which captures a theme and involves qualitative richness (Nowell et al., 2017).

The focus was on the chosen content-related situations in which the students more explicitly demonstrated knowledge of technology. This involved situations where students explained the technology perceived in the VR experience to fellow students and the teacher. The utterances were transcribed and written down. All transcripts were translated from Swedish to English. This material would be used for the in-depth analysis of the student's knowledge of technology with supportive 360° VR images (197 minutes). In this phase, the analysis process focuses on deductive coding based on DiGironimo's five dimensions of technology (Nowell et al., 2017), with a specific focus on the first research question.

An in-depth analysis of the chosen excerpts was conducted. Accordingly, utterances were analysed concerning the framework presented by DiGironimo (2011). To illustrate how the students absorb technological knowledge, some examples of extracts from the transcribed empirical work were chosen, where the students show their understanding of technology. It became possible to identify situations where the students' interactions correlated with the images in the VR experience (cf. Efstathiou et al., 2018; Livatino et al., 2022; Sala & Sala, 2005). In this phase of analysis, DiGironimo's framework was found to be wide, as all five dimensions were represented in the small-group interactions.

While the second research question aims to investigate how VR images support students' small-group interactions, concerning the history of technology, I felt it was important to add another perspective on the students' interactions. Following this step, the analytic procedure continued with a detailed evaluation of the earlier chosen excerpts, in line with the framework defined by Nennig et al. (2023). The framework was the starting point for further elaborating on the students' interactions in this study, describing students' discursive moves while working through an assigned task. The discourse analysis primarily builds on the three-level characterization of students' interaction discursive moves (SIDM).

Each excerpt was read thoroughly to ensure a comprehensive understanding of the content. The excerpts were systematically organised according to the first level – *type of interaction* –as the initial dimension of analysis. This level is identified by how students broadly interact with each other. This was followed by a second, detailed reading, after which the excerpts were recategorized based on the second level – *primary intent* – of the interaction, describing the purpose of the students' posts in the discussions. A third reading was then done to classify each excerpt according to the third level – *nature of utterance* – which constituted the third analytical dimension of the framework. This is characterized by how students display a specific *primary intent* and what purpose the students' utterances serve for the small-group interactions.

Finally, the students' discursive movements were examined, focusing on the interplay between everyday language and subject-specific language (Nygård Larsson & Jakobsson, 2017). To identify how the teacher tries to bring understanding and create communicative situations, the teacher's discursive moves were analysed – categorised as foundation, initiation and perpetuation (Bansal, 2018). This approach facilitated a nuanced understanding of the interactions present within this learning environment.

Table 1. Thematising of the students' utterances related to DiGironimo (2011)

The nature of technology	**Students' utterances**
Technology as an artefact	*Stove, oven* *Kitchen, cottage* *Stuff* *Where is the toilet?*
Technology as a creation process	*Certainly, cook there.* *Cooked cold food.* *It is made from wood.* *Shoes are made from wood.*
Technology as a human practice	*They cooked food.* *You open the door so and so and then you close it – so* *They had a coffin as a wardrobe.* *Where are they pooping and peeing?*
The history of technology	*So old.* *It was a long time ago.* *Old stove, how the old stove looks like?* *What did the humans' clothes look like, I want to know that.*
Current role of technology in society	*[…] stuff we need.* *Help us to survive.* *I have one of these at home.* *I have one that comes with wheels.*

Findings and analysis

Thematising the students' utterances

The first part of this section focuses on the first research question and categorises students' utterances according to the five dimensions of DiGironimo's framework. The findings are presented in the form of short utterances from longer interactions. It was clear that the small group interactions gave opportunities for students to demonstrate knowledge of technology within all dimensions of the framework (see Table 1). This is not in line with previous research (e.g., DiGironimo, 2011; Eliasson, 2023a), as the dimension of the history of technology became visible in this study's interactions.

Students' utterances related to DiGironimo and VR

To approach the second research question, regarding whether VR promotes students' understanding of the history of technology, an in-depth analysis of the student interactions related to the teacher's question "How technology used to be?" was conducted. The displayed excerpt serves as a typical example of how the students in group interactions demonstrate knowledge of the dimension of the history of technology. These utterances can be categorised as identified perspectives of technology, in line with DiGironimo (2011). In addition, Efstathiou et al. (2018), Livatino et al. (2022), and Sala and Sala (2005) argued that VR environments can create immersive experiences of a historical situation and make the presented information easier to understand.

Excerpt 1: How technology used to be?

V1	Cy	*So old. Everything is wood, and porcelain.*
V2	Moha	*There was something in the door.*
V3	Cy	*Do they have metal? Do I think or…?*
V4	John	*Mmm…no, maybe.*
V5	Cy	*They have porcelain. I think they have concrete as well.*
V6	John	*I know and there is stone on the floor.*
V7	Cy	*I don't think it's concrete, it's thick porcelain.*

In *"So old"*, Cy refers (V1) to what he considers an old environment in the image displayed. The utterance implies that he perceives that technology might have been improved as it is old and, compared to new technology, everything here is made of wood and porcelain. He argues that there are two different materials in the displayed image, which could be interpreted as containing smaller parts of an artefact, for example, constructing materials. In that case, *"Everything is wood, and porcelain"* (V1) could be considered parts of the displayed technology; therefore, this could be categorised as technology as a creation process (TC). Materials are considered a small part of artefacts, and therefore, technology is considered a creation process. Instead of responding, Cy continues discovering and identifying materials (V3), *"Do they have metal?"*, which can be related to the image displayed. He states (V3) *"Do I think or…?"*, which is more likely a question aimed at himself than at the group to elaborate on. John's (V4) *"Mmm…no, maybe."* is a responding answer to Cy, which allows him to follow up with (V5) *"They have porcelain. I think they have concrete as well"*. Finally, John's statement (V6), *"I know, and there is stone on the floor"*, is a response to Cy's utterances on materials in the VR environment. Thereby, indicating that they agree on the materials, John adds stone as another material he identifies. Cy reflects (V7) *"I don't think it's concrete, it's thick porcelain"* to reach a final decision on materials in the displayed VR image. The students distinctly refer to the VR image displayed to them, which indicates that the freedom to look at what they find most interesting could motivate and engage students to actively interact around a topic that they identify and initiate themselves.

In the following excerpts, the students' questions stand as typical examples of how the VR environment possibly affects their thoughts on the history of technology. These questions can be utilised by the teacher to create communicative situations where the students elaborating on the historical technology can continue.

Excerpt 2: The history of technology related to the VR experience

V8	Jovan	*What did the humans' clothes look like? That I want to know.*

In the example, Jovan initiates a question (V8), *"What did the humans' clothes look like?"*, related to the history of technology and, in doing so, the dimension of technology as artefacts, *"clothes"*, and technology as a human practice, through humans' interaction with the artefact, becomes visible. This question comes out of group discussions regarding images of the chest and the wardrobe and the fact that humans in the 19th century could use chests as storage for their clothes, whereas, in the 21st century, humans in a Western context commonly use wardrobes or dressers.

Excerpt 3: The history of technology related to the VR experience

V9	Nono	*Is there a bathroom?* *Where are they pooping and peeing?*

Nono looks at the enveloping image and asks two questions (V9): *"Is there a bathroom? Where are they pooping and peeing?"* which is prevalent in other groups as well. This indicates that this issue is relevant to some of the students in the class. Like Jovan's question, these questions could be related to the dimension of the history of technology. Further, the pooping and peeing issue is also most relevant for this student. Nono seems to want to learn about how these issues were solved in the 19th century. This is closely related to technology as a human practice as *they* could be interpreted as people and, following, that humans utilise the toilet.

Table 2. Identified perspectives on the history of technology related to VR images

Identified perspectives	Examples of utterances
Technological systems The students described artefacts and a conceivable technological system and questions related to a historical perspective.	*Where are they pooping and peeing?*
Materials The students identified various materials in the VR images related to a historical perspective.	*Everything is wood, and porcelain.* *Do they have metal?* *They have porcelain. I think they have concrete as well.*
Historical perspective The students perceived the history of technology.	*What did the humans' clothes look like?* *So old*

The excerpts above focus on students' statements when discussing the VR images. These utterances can be related to the dimension of the history of technology and the teacher can guide the students to make the information understandable; that is, to highlight what is and is not worth noting in this activity.

The students' interaction discursive moves

The above analysis indicates that students' utterances are more complex than the dimensions of DiGironimo's framework, which suggests that the second research question – how VR images possibly support students' interactions – needs to be further examined. Hence, it was evident that another perspective was required to investigate students' discursive moves (Nennig et al., 2023) during an assigned task. The students' discursive moves are denoted in italics throughout the paper. Excerpt 4 illustrates how the students interact when using VR images as support. In this excerpt, it was possible to highlight the aspects of **type of interaction**, **primary intent** and **nature of utterance** in the framework suggested by Nennig et al. (2023). This will be described below.

The intent of the interaction, presented by the teacher, indicates that the students are actively discussing the assigned task; this type of interaction could be regarded as *on-task*. Throughout the small-group interactions, the students are sticking to the assigned task: *on-task*.

In the following example of an *on-task* interaction, the teacher utilizes a 360° enveloping VR image from the inside of a house built in the 19th century. The teacher perpetuates interest in the assignment by encouraging the students to elaborate and exchange ideas about the image displayed.

Excerpt 4

U6	Jovan	*Check out, the shoes are also made of wood*
U7	Olivia	*Everything is made from wood*
U8	Jovan	*Except for the floor, it is..*
U9	Olivia	*We lived there…*
U10	Ruth	*Oh my God*
U11	Jovan	*Every single thing in the house is made from wood*
U12	Teacher	*(Displays an image of a modern vacuum cleaner)*
U13	Jovan	*Vacuum cleaner*
U14	Amir	*Is it a vacuum cleaner?*
U15	Teacher	*What did the vacuum cleaner look like in the past?*
U16	Olivia	*It is only with sticks and then they do like… (showing how a broom is used)*
U17	Jovan	*Yeah, sticks*
U18	Ruth	*Which are tied*
U19	Olivia	*Everything is made from wood*
U20	Teacher	*Can you imagine that we have come from the broom to …*
U21	Jovan	*…the vacuum cleaner*

The teacher initiates further discussion by displaying an image of a modern vacuum cleaner as opposed to the broom in the enveloping 360° image (U12). The displaying of images is a way to guide the students further in understanding the history of technology, as well as holding on to the interest the students showed in the class discussions. The initiation moves, as the teacher points at the broom (signalling); this involves stimulating the students' interests and enlightening them with different perspectives, which is possible as the two timelines are presented alternately to the students. Signalling in a VR environment can support students' learning, as it provides them with attentional guidance. Jovan (U13) and Amir (U14) are both *on-task* in their interaction. However, both of them also interact with the teacher about the displayed image. Here, the teacher perceives an interest and engages the students by addressing (U15) *"What did the vacuum cleaner look like in the past?"*. The question initiates another perspective on technology, as it highlights that the vacuum cleaner has a history and has been developed throughout history. In this case, the students are enlightened by another perspective of technology: experience-based technology and microtechnology. This initiation move stimulates the students' interests and provides them with different perspectives, which becomes clear as the students (U16–U19) are *on-task* in their interactions. Now, to keep the student's interest in the topic, the teacher asks (U20) "*Can you imagine that we have come from the broom to …"*, to stimulate imagination and thus obtain further perspectives on the topic. However, this question only gives one answer, which does not allow any students to elaborate further on the historical development of the vacuum cleaner.

The discursive moves, the *primary intent*, *commenting* and *initiating* are present in Jovan's statement (U6) *"Check out, the shoes are also made of wood"* as he makes a personal remark that possibly engages and initiates the discussion in the group. Olivia's (U7) *"Everything is made from wood" contributes to the discussion* as a response to Jovan's initial exclamation. It is also conceivable to identify her utterance as *commenting* on Jovan's utterance as she adds a personal remark. Jovan *initiates* (U8) the group to look at the floor, which *contributes to the discussion* and further investigates the environment. Olivia is a bit *off-task*, by *commenting* (U9) *"We lived there…"*. This could be Olivia showing her understanding of the historical development of a house. However, this passes unnoticed by the rest of the group. Ruth's exclamation (U10) *"Oh my God"* might be her *acknowledging* Olivia's idea of us living in the displayed 19th-century house. Jovan *concludes* the discussion by uttering (U11) *"Every single thing in the house is made from wood"*.

After the teacher showed the broom in the enveloping 360° VR image and displayed a 2D image of the vacuum cleaner, both Jovan (U13) and Amir (U14) *commented* on the issue. The *question* by Amir *"Is it a vacuum cleaner?"* requires his fellow students to respond during the activity. The history of technology comes into focus as the teacher asks the question (U15) *"How did the vacuum cleaner look like before?"*. Here, Olivia (U16) is *commenting* on how the broom is functioning and used. She also *initiates* a discussion on both the function and the material a broom is constructed of, which is a way of *contributing to the discussion* as she adds a perspective of technology and, by that, likely *concludes* that the broom is technology. Jovan (U17) acknowledges Olivia's input by agreeing and *commenting "Yeah, sticks"*. Ruth (U18) *contributes to the discussion* and *concludes* as she ends Jovan's utterance on the broom. Again, Olivia (U19) makes a personal remark on the material in the environment *"Everything is made from wood"*, which could be considered her *conclusion* to the discussion. By stating (U20), "*Could you imagine that we have come from the broom to …"* the teacher tries to initiate a discussion on the relationship between the vacuum cleaner and the broom. However, the question spurs a single answer *"…the vacuum cleaner"*, which is Jovan (U21) *concluding* the sentence.

The nature of the utterances of Jovan's first statement (U6) could be identified as him *presenting a claim* as he suggests an answer to the teacher–initiated activity. Olivia (U7) *repeats* parts of Jovan's utterance *"Everything is made from wood"* and adds that not only the shoes are made of wood but everything. Jovan's statement (U8) *"Except for the floor, it is …" builds* further on Olivia's statement and tries to *present a claim* but is interrupted by Olivia (U9), who makes a personal remark and adds a historical perspective, which probably is built upon *past experiences*. Ruth (U10) responds to Olivia, which probably *motivates* and brings some encouragement to the group. Jovan (U11) *repeats* and *builds* on the other participants' utterances and concludes that *"Every single thing in the house is made from wood"*.

The two historical timelines are displayed as the teacher (U12) adds a 2D image overlayed on the image of the broom. Here, it is feasible to recognise that Jovan (U13) *provides information* to the whole class as he interacts with the teacher more than with his group. However, the utterance by Amir (U14) is more relevant to the group discussion as he seems to *seek* and *request clarification* from fellow students or the teacher that his interpretation of the overlayed image is correct. Amir is also *reporting* a question to move the discussion forward. His question is not further elaborated on because the activity is moving forward when the teacher adds another perspective on technology into the discussions (U15). Here, Olivia (U16) is engaged in the interaction by contributing a *non-verbal interaction* as she physically participates and shows how the broom is functioning. Olivia also tries to understand and *process the information* she gets. By doing so, she *provides information* to the discussion, which probably moves the group discussion forward. Jovan (U17) voices *agreement* with Olivia's utterance on the *"sticks"*. Ruth's utterance (U18), *"Which are tied",* could be considered her *building* on Olivia's utterance and expanding her ideas. She also *processes information* and transforms the information given by Olivia to try to comprehend and develop understanding. Finally, *information* is *provided* as Ruth adds a perspective on how the broom was made. Olivia (U19) *summarizes* by *building* and *agreeing* on earlier stated utterances in the group that all things in the VR environment are made of wood. After the last question asked by the teacher (U20), Jovan (U21) *summarizes* and concludes the sentence.

The third level, the *Nature of utterance*, gives a more nuanced view than the second level, *primary intent*. In some cases, these discursive moves were primarily related to one primary intent, such as *summarizing* and *commenting*. Most of them were related to several discursive moves, for example, *completing*, *building*, and *providing information* related to the primary intent – *contributing to the discussion* (see Table 3).

Summary of the students' interaction discursive moves

In the excerpt, it is feasible to identify that students can keep focus in the discussion: *on-task* (the first level – *type of interaction*), indicating that they are engaged in the assignment given to them. The second level, *primary intent*, is best exemplified, in this class, in the moves of *concluding*, *commenting* and *contributing to the discussion*. *Concluding* is characterized by statements that summarize the exploratory conversation, whereas *commenting* involves personal remarks and understanding of an earlier statement. When a student *completes* or *builds* on another student's utterance, this is regarded as a *contribution to the discussion*. *Building* is always displayed alongside other *nature of utterance*, such as *initiating*. Another aspect of discursive moves is *questioning*, which often occurs in small groups. The questions could be *initiated* as *seeking explanation* and *clarification* or just as an interest in moving towards a deeper understanding of a specific area, such as the mentioned issue of where the toilet is (cf. Nennig et al., 2023).

Table 3. The relation between the discursive moves, Primary intent, and Nature of utterance, in excerpt 4 (Nennig et al., 2023)

Number	Primary intent	Nature of utterance
U6	*Commenting* *Initiating*	*Presenting a claim*
U7	*Contributing to discussion* *Commenting*	*Repeating*
U8	*Initiating* *Contributing*	*Building* *Presenting a claim*
U9	*Commenting*	*Past experience*
U10	*Acknowledging*	*Motivating*
U11	*Concluding*	*Repeating* *Building*
U12	*Teacher initiates interaction*	
U13	*Commenting*	*Providing information*
U14	*Commenting* *Questioning*	*Seeking clarification* *Requesting clarification* *Reporting*
U15	*Teacher initiates interaction*	
U16	*Commenting* *Initiating* *Contributing to discussion* *Concluding*	*Non-verbal interaction* *Processing information* *Providing information*
U17	*Commenting*	*Agreeing*
U18	*Contributing to discussion* *Concluding*	*Building* *Processing information* *Providing information*
U19	*Concluding*	*Summarizing* *Building* *Agreeing*
U20	*Teacher initiates interaction*	
U21	*Concluding*	Summarizing

Discussion

The present study aimed to investigate primary students’ developing knowledge of the nature of technology through verbal interactions with supportive images in a virtual reality learning environment. To answer the first research question, the framework suggested by DiGironimo was applied. The findings indicate that the students expressed a wide understanding of what technology is. In the interactions, students discussed and thought together about technology, which promoted many perspectives on technology to emerge. This highlighted the variation in the students’ utterances, demonstrating their knowledge of mundane technology verbally. This is not aligned with studies conducted by DiGironimo (2011), Eliasson et al. (2023a) and Liou (2015), where the historical dimension of technology was not clearly expressed by the students. In this study, by showing VR images and the teacher asking questions, students engaged in discussions about the history of the technology, aiming to deepen their understanding and knowledge in this field. In analysing this study's results, it became evident that students' knowledge could be categorized. However, since all dimensions of DiGironimo's model were covered in the analysis of their discussion, I displayed greater details and nuances in their utterances than the model accounts for. Consequently, their discussions are more complex than the model can capture. This means that, to answer the second research question and to achieve a deeper understanding of how the students demonstrate knowledge of the nature of technology, I employed a discursive analysis. The in-depth discourse analysis involved the approach of mapping the students' interactions, including discursive moves (Nennig et al., 2023).

Through signalling (Albus et al., 2021) and attentional guidance, the teacher emphasizes aspects of technology that stimulate students' interest and support them in maintaining their focus on the assigned task thereby ensuring they remain on-task (Nennig et al., 2023), thereby bringing focus to the history of technology and encouraging them to examine and further elaborate on a specific topic. A previous study (Foreman et al., 2008) suggests that younger students are somewhat disadvantaged in using VR in learning. However, the results of the present study suggest that the teacher's guidance through, for example, signalling enables younger students to discuss the content with the support of VR and thereby leads to a wider understanding of technology. The added VR images created conditions for the comparison of two historical periods.

To approach the second research question, I was able to identify the students' discursive moves during VR learning activities and discover patterns related to students' interactions related to the history of technology. The students move back and forth between different discursive moves, which often leads to exploratory conversations about the history of technology. Through the interaction with VR images, it becomes evident that the students offer new viewpoints, especially regarding technology material composition and functionality. For example, many students contribute to moving the discussion forward (primary intent) by adding or initiating (the nature of utterance) new perspectives on technology or building on other's utterances (Nennig et al., 2023).

The results indicate that students jointly construct knowledge (cf. Nennig et al., 2023) about the history of technology, particularly through dialogues initiated by fellow students that facilitate agreement or disagreement, thereby advancing the discourse. This learning process enables them to further explore specific topics, such as the historical aspects of cooking, through collective reasoning and elaboration. Students' contributions to the discussion sometimes appear insubstantial as they engage less than the other students. However, their contributions are essential as their questioning or statements could advance the discussion. This could encourage the students to jointly widen their understanding of the history of technology, demonstrating that everyone can learn from each other. Furthermore, the findings suggest that students have an enhanced understanding of technology's emerging technologies and their advances (cf. Eliasson et al., 2023b), as exemplified when students and the teacher discuss which of the broom and the vacuum cleaner was preferable. In that interaction, the perspective of technology as experience-based technology and microtechnology (de Vries, 2016) is displayed by the teacher and acknowledged by the students.

In the present study, the analysis of the findings indicates that VR images, alongside the teacher's guidance, through signalling, informing, and questioning, appear to promote students' examining and jointly elaborating ideas of the historical dimension of technology. As the students interact with VR images, they spontaneously verbalize what they experience, which could enhance their engagement. The ability to perceptually focus could enhance the students' experience in VR, as it is a visual phenomenon and an individual experience (cf. Ihde, 2002). Conclusively, adding VR images to a learning environment could bring engagement to the classroom activity and support a mutual focus (cf. Eliasson et al., 2023a) on a topic such as technological artefacts. Teachers displaying an image is a way to emphasize differences and to perpetuate (Bansal, 2018) a discussion on the actual topic, for example, the history of technology. Moreover, providing VR images concerning two historical timelines appears to facilitate an exploration of the history of technology, as exemplified by students' questions about details within the VR environment, such as the location of toilets. The opportunity to move to another environment is one of the key strengths of utilizing VR experiences in learning situations, fostering a sense of 'presence', which is the illusion of being moved to another place, time, or setting, as articulated by Slater (2018). I suggest that students not only engage with but also enjoy the immersive aspect of VR experiences, a point emphasized by Petersen et al. (2022). Therefore, it is not possible, as Foreman et al. (2018) suggested, to conclude that VR contributes to less understanding of a subject area. However, different materials or the lack of something are discussed concerning the VR images, which indicates students verbalising pre-knowledge of technology. These aspects can lead to further discussions in class.

Didactical contributions

The use of VR images can provide technological context (cf. Lind et al., 2024; Lind et al., 2019), which can support verbal interactions and students' ability to understand the history of technology. Thus, images and verbal communication could mediate technological knowledge about technology. In the present study, the VRLE offers opportunities for students' self-determination to control and improve their conversation in a way they want, which causes several perspectives of technology to arise. Presumably, the students' continuous thinking "aloud" together enables the teacher to identify questions and claims to be further elaborated on. Consequently, providing framed VR learning activities could make certain school technology subjectivities possible and students' everyday experiences countable. A more precise vocabulary could advance students' concepts of how and why technology has evolved throughout history, involving past, present, and future perspectives. Given the young age of the students, images of everyday mundane technology were used to create a familiar discourse for the interactions. Additionally, the possible inspiration from the visual support to activate the students' prior knowledge can be used to expand their understanding of technological content. The historical perspective of technology can teach us how to manage challenges today and in the future, which can promote emerging technological knowledge.

Through the contributions of this study, new questions regarding advanced technology in education emerged. Future research could focus on the effects of applying artificial intelligence (AI), augmented reality (AR), and virtual reality (VR) in the technology classroom, for example, to engage students in verbal interactions and facilitate their emerging technological literacy.

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29.2

The AI generative text-to-image creative learning process: An art and design educational perspective

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Abstract
In today's constantly changing world technological developments in artificial intelligence (AI) can induce educational visions of both utopia and dystopia. New technologies and communication platforms can provide new forms and possibilities of learning. Creating an image has historically mostly been a human process of using knowledge and application of technique that demanded training. This image-making process changed with the invention, development and spread of the photographic camera, when creating a detailed visual representation of reality became a possibility without a complex process of craftsmanship and artistry. The nature of visual art changed but the visualisation of ideas and prefigurative thoughts could not necessarily be captured by a camera. With the development and spread of AI text-to-image generation, can this change the need for competency to visualise ideas in the way the camera changed the need for drawings and paintings as visual representations? This study explores how AI text-to-image generators can contribute to and change art and design education. We conducted exploratory experiments where we tested a variety of AI text-to-image generators and explored the outcome of using different generators, prompts and settings. Reflections were written down throughout the process. This was combined with an online ethnography on a text-to-image community. Different potentials of learning were identified, as well as issues of interaction and possible contexts of use. The results are discussed in a future learning context.

Keywords
Artificial intelligence, Text-to-image generation, Art and design education, Visualisation

Introduction
Education and the way we learn needs to adapt to society. Constant changes in technology have led to new cultures and places of learning (Thomas & Brown, 2011). Artificial intelligence (AI) represents a digital technology that has great power to change society. With the rapid development of AI technology, educators need to adapt to emerging technology that can potentially change how we work and produce. Artificial intelligence text-to-image technology has been developed since 2014 and increased in popularity after the introduction of DALL-E in 2021 (Cetinic & She, 2022). In 2022, this development accelerated rapidly with the launch of services such as Midjourney, OpenAI's DALL-E 2, Adobe Firefly, and Stable Diffusion. With the widespread use and rapid technological development, there is a need for research to critically look at the possible use and application of AI text-to-image generation. In this study, we ask: How can AI text-to-image generators contribute to and change art and design education?

Background

A short history of visualisation

Prefigurative thinking is seen as an important part of what constitutes being human (Fry, 2012). The prefigurative thought of an idea or concept can be materialised through medium and technique. Doing this, and also being good at it, are no easy tasks. It takes time to develop the knowledge and skills to produce traditional visual forms that constitute sensorimotor activities, such as drawing and painting. There were no quick-fix methods for creating quality visualisations before the introduction of photography. The process of image creation underwent a significant transformation with the advent, progress, and widespread use of the photographic camera (Gombrich, 1982). The camera enabled the creation of highly accurate visual depictions of reality without intricate craftsmanship and artistic techniques. However, as prefigurative thoughts cannot necessarily be captured by a camera, there is a need for skills in drawing and illustration (Nielsen, 2013). This raises the question if the development and spread of AI text-to-image generation can change the need for competencies to visualise ideas in the way the camera changed the need for drawings and paintings as mimetic visual representations.

Text-to-image generation technology

There are different text-to-image generative systems, but what they have in common is that textual inputs called *prompts* are interpreted by a system before images are created. The systems are trained on large datasets of text-and-image pairs from the web (Abdallah & Estevéz, 2023; Hutson et al., 2024). A prompt can lead to unexpected results, but at the same time the different models, such as Midjourney and OpenAI (DALL-E 2), provide tips on how to alter the style or format by adding specific terms. These tips can help one to affect the outcome and, by adjusting the prompt input, one can increasingly control the image-making process. We mostly used Midjourney version 4 in the beginning of our study. Our explorations coincided with significant developments of the generators, such as the release of Midjourney Version 5.1 and solutions to recurring issues such as the depiction of fingers (Verma, 2023). Later we have mostly used Midjourney version 5 and 6, as well as different non-payment generators such as Krea, Lexica, and Stable Diffusion Online. Due to the rapid development of the technology, we are more concerned with the overarching concept of AI text-to-image generators than specific technical aspects.

A changing art and design education providing competencies for the future

In Norwegian primary and lower secondary school, Art and crafts is a compulsory subject. The 2020 curriculum revision ensures a more future-directed education, in part by making technological use and programming more visible (Norwegian Directorate for Education and Training, 2020). The extensive development of AI in recent years renders it impossible to predict what the future will look like. Rather than transferring knowledge teachers must facilitate learning processes regarding future challenges. This necessitates that educators possess a distinct combination of knowledge, skills, and attitudes to use technologies effectively. This is often referred to as professional digital competence (Kelentrić et al., 2017). This is not just about having technical skills; it also involves understanding how to integrate technology into teaching and learning in ways that add value and enhance students' understanding. This also includes shifting the focus from teacher-led to learner-centred processes. The use of technology should therefore be determined by the needs and demands of the subject matter rather than forcing the subject to adapt to the technology. Technological tools can aid in the illustration of complex concepts, facilitate broader discussions, and enable students to explore and learn at their own pace (European commission et al, 2017). The role of a digitally competent teacher also involves making responsible decisions about privacy and data security, understanding the ethical implications of technology use in the classroom, and fostering a respectful and inclusive digital learning environment. The 2023 GEM report, *Technology in education: a tool on whose terms?* (Global Education Monitoring Report Team, 2023) published by UNESCO argues that digital technologies must be used to support an education based on human interaction rather than aiming at substituting human interaction with digital technologies, ensuring learning processes where the student's learning is in focus. Artificial intelligence will challenge schools' teaching and assessment practices, and a new government strategy (Kunnskapsdepartementet, 2023) requires schools to adopt AI in order to gain a basic understanding of how AI works, its solutions, and its limitations. Thus, teachers and students need sufficient digital competencies to use AI in an exploratory way, with curiosity, critical thinking, and ethical awareness.

Literature review

Widespread use of AI text-to-image generative technology is fairly recent. Naturally, this is an emerging research field where much of the literature is shared as pre-prints in non-peer reviewed archives. We have however chosen to limit our scope of this literature review to only include journal articles or conference proceedings. At the time of the study, there is little research on the use of text-to-image generative technology in K-12 arts education. We have therefore included research that explores the use of this technology in art and design processes in general.

In the literature, we have seen several ways of incorporating AI images into creative processes. Chen et al. (2019) conducted a case study on the design of spoons. In the ideation phase, participants used a GAN-model that combined selected images of leaves and spoons, to generate a multitude of synthesized images. The participants drew their spoon-designs by hand later. Compared to the control group, who only used Google in their ideation phase, the AI-participants produced a larger quantity, variety, and novelty of their designs (Chen et al., 2019). Liu et al. (2023) also investigated product design. They implemented the AI text-to-image generator 3DALL-E into a 3D-modelling program, which meant that their participants worked with text-to-3D. Participants were enthusiastic about the use of AI, especially for ideation, as it was a quick and easy source of inspiration and helped them avoid design fixation. However, some participants felt like the AI was driving the design process, as they adapted their creative process to the output (Liu et al., 2023). Mikkonen (2023) explored how Midjourney could be used to generate mood boards. He concluded that the AI quickly produced high quality images that were visually usable in design but was concerned with potential copyright issues (Mikkonen, 2023).

The use of AI text-to-image generators have also been explored in the context of visual art. Hutson and Lang (2023) incorporated AI into a digital media course, in which the students' generated images that were modified further in image editing software. The students found the AI to enhance their outcomes, as it helped them to structure and visualise their ideas. They were however unsure about future use, as they perceived that the AI did not surpass human creativity, but that the images had 'a similar, postcard-like quality that hindered their artistic potential' (Hutson & Lang, 2023, p. 11). Lyu et al. (2022) compared AI-generated images resembling oil paintings made by artists and non-artists, along with a questionnaire answered by the participants. While the non-artists were excited about making images that looked excellent and perceived that the AI helped them to visualise their imagination, the artists were dissatisfied due to a feeling of losing control of the process. Participants mentioned being surprised by the images that were generated, and two artist participants likened it to opening Pandora's box. Finally, in an expert ranking of the outcomes, the images made by non-artists obtained slightly more votes (Lyu et al., 2022). Ko et al. (2023) interviewed visual artists after they had learned about and tested DALL-E. The participants saw a great potential for using AI in early phases, such as to quickly visualise ideas, and generate reference images or material for visual communication. They did however also experience that the articulation of their ideas into prompt could be time-consuming and that they may lose the delicate mental imagery while finding the correct text-prompt (Ko et al., 2023). Vartiainen and Tedre (2023) conducted a similar study, where pre-service craft teachers and teacher educators participated in a workshop followed by a joint discussion. Participants saw opportunities for using AI to visualise impossible ideas and mentioned that it might support small children to articulate vague ideas. Coming from the field of craft, they were however concerned about the lack of embodiment and engagement with materials in the creative process (Vartiainen & Tedre, 2023).

Among the recurring findings is that the AI may stimulate ideation processes by quickly generating unforeseen suggestions that can be a source for inspiration and references. AI was also found to support the visualising of ideas regardless of craft skills. There are however several concerns, regarding the constraining of creativity, copyright issues, and the lack of embodied engagement during the process.

Methodology

We have chosen a qualitative approach, combining explorative experiments and online ethnography. This generated data in form of notes and image material. As this article builds on a conference paper presented at the PATT23 conference (Ringvold et al., 2023), the study consisted of two phases. The first phase was an intensive six-month period from November 2022 to May 2023, when we finished the first paper. The second phase was a continuous exploration from May 2023 to April 2024, where we have continued with explorative experiments individually, but also included other participants in workshops or teaching at our university.

Explorative experiments

Explorative experiments, based on Dyrssen (2010), has been the main method used in this study. Dyrssen states that, while explorative experiments cannot be validated, they allow the researchers to 'shake up ingrained patterns of thought; provide quick feedback, increased curiosity, and discoveries of hidden possibilities; reveal possible links and points that need to be mapped; and get the creative process moving forward' (Dyrssen, 2010, p. 229). Due to the rapid development of AI text-to-image generators, such explorations of the technology have given us valuable insight into how it can contribute to and change art and design education.

In the explorative experiments, each of the four authors tested AI text-to-image generators and explored the outcome of different generators, prompts, and settings in use. In the autumn of 2022, we had little to no experience with AI text-to-image generators. The prompts were therefore written based on our own imagination and curiosities, sometimes choosing to follow interesting idea strands. We acknowledge that our abilities to prompt, and what we prompt have naturally evolved throughout the period of this study. The combined variety of prompt inputs, ranging from the abstract to the concrete, is reflected in the examples presented in the results section.

Throughout the process of explorative experiments, we wrote down our reflections and saved image material that comprise the empirical data. We shared experiences from the explorations of the AI text-to-image generators in frequent meetings. In these discussions, we also drew on our backgrounds in design and education. We have approximately 10 years of teaching experience each, and combined this covers teaching at all levels, ranging from Year 4 (nine-year-olds) to university level. Through reflective dialogue, we discovered central issues regarding our experiences of AI text-to-image generators, as well as staking out a path for further experiments. While these meetings were more frequent and structured during the first intensive phase, we have continuously shared our experiences and reflections throughout both phases.

During the second phase of explorative experiments, we also conducted three workshops. These had a diverse range of participants, as one was for Art and crafts teachers (approximately 80 participants), one for students in Year 6 (11-12 years old) (6 participants), and one for colleagues from all faculties of our university, including retirees (12 participants). From these workshops, we have made observation notes, taken photographs, and saved generated image material. We have also implemented the use of text-to-image generators in our teaching at the Art and design teacher education at BA and MA levels. Our experiences from working with these participants have become an increasingly important part of our shared reflections in the meetings during this second phase.

The images in this paper are created with Midjourney Versions 4, 5 and 6. Version 4 was the default model from November 2022 to May 2023. Version 5 was released on 4 May 2023, and Version 6 has been the current default version since February 2024 (Midjourney, n.d.-b).

Online ethnography

Midjourney is accessed through a server on the online community platform Discord (Discord, n.d.; Midjourney, n.d.-a). This facilitates interaction between users, as the generated images normally are visible also to other users. This led the first author to conduct an online ethnography, as described by Hart (2017) and Winter and Lavis (2020) in the text-to-image community of the Midjourney server. The online ethnography was conducted at three different timepoints during the first, intensive phase, capturing users' interactions through screenshots of images and text.

Thematic analysis

The empirical material from the explorative experiments and the online ethnography were analysed through a thematic analysis as derived from Braun and Clarke (2022). The reflective notes were organised and temporarily coded based on the similarity of the content. We identified these themes and similarity of content related to AI text-to-image generators' potential for learning, limitations, and hindrances, as well as issues of interaction and possible contexts of use. The notes were then read again through the lens of the emerging themes. The themes were further developed and refined through defining, renaming, and merging themes (Braun & Clarke, 2022). The results from this analysis are presented and discussed in the following section.

An art and design educational perspective on the AI text-to-image creative learning process

The results and discussion are presented in a bilateral manner of learning potentials on the one side and learning obstacles on the other. However, the identified qualities are not necessarily either a potential or a hindrance to learning; they can be both at the same time. Firstly, we present two models of how we identified the AI text-to-image creative process in a learning perspective.

Modes of creation processes from a learning perspective

Creating visualisations using text-to-image generators is a cyclic, iterative process. We identified this image creation process as consisting of several stages, as visually presented in Figure 1. The first of these is the idea stage. This can be a prefigurative thought at the beginning of a process, the refinement of previous ideas, an adaptation of a previous idea, or a surprising new idea that originated from a previous process. Taking the step from idea to a written prompt, one needs to shape the visual idea or concept through articulation (stage 2). After feeding the prompt in writing (stage 3), a black box process (Bunge, 1963) gives one the results (stage 4). Results can be implemented (used) or aborted (left unused). They can also be refined, adapted, or used to start new ideas in a cyclic process. These post-result actions are triggered by how the prompter evaluate the prompts, identifying what needs modifying, deleted, or added in the prompt. An example of this is when using terms with multiple meanings or specific cultural references in the prompts. While this might not be clear to the user initially, what needs to be modified in the prompt is usually easily detected in an evaluation of why the generated image differs from the users' idea.

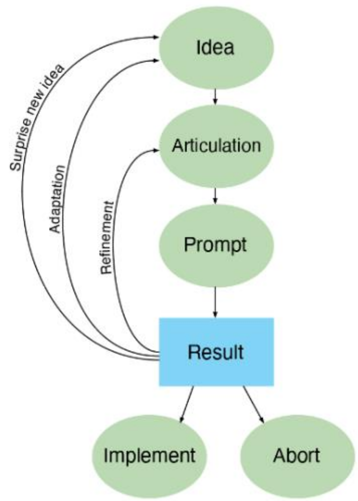

Figure 1. The identified image creation process using AI text-to-image generation.

In addition, we propose an understanding of the learning process that takes place while using AI text-to-image technology (Figure 2). In a cyclic, interactive learning process between the human user and text-to-image AI technology, a variety of actions can take place in an interchange between A: Seeing opportunities and B: Finding limitations. These actions can contribute to the cyclic development of learning processes of varying length. Variations also apply to the actions involved in the cycle. As signified by the multiple double-pointed arrows in the model, the actions do not take place in a linear fashion, the user rather moves between some or all of the actions during an interactive learning process.

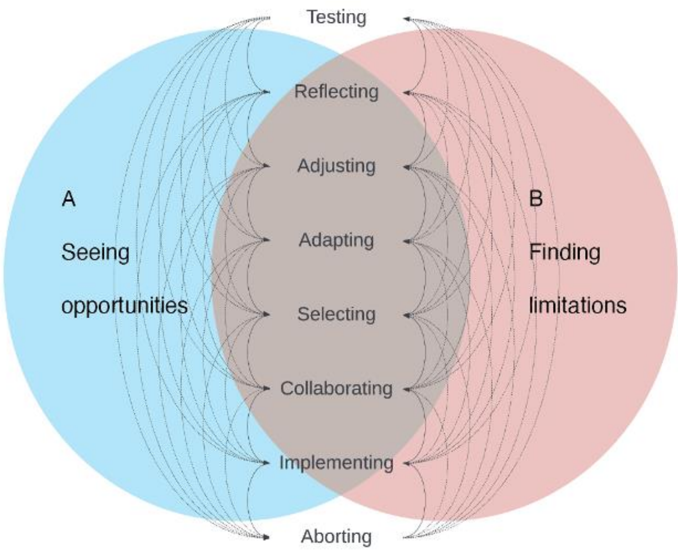

Figure 2. A proposed representation of the cyclic human user and AI text-to-image interactive learning process.

Potential learning opportunities

In this section, the identified potential learning opportunities are presented and discussed.

Enabling visualising abilities, a democratisation of visualising?

Artificial intelligence text-to-image technology provides the user with a powerful tool to generate visualisations without much effort. This ease of access to visualising allows for playful image-making. The image creation could, especially at the beginning of using the technology, be about testing limits, and seeing what is possible. Using this technology, students can possibly push their own boundaries of imagination. The ease of access can trigger a willingness to try and experiment with creative image making. Early adolescents may experience a more critical view of their produced drawings, as described by Lowenfeld (1947). For the non-professional image creator, text-to-image generation can provide a beneficial training ground and a tool for visualising. We see this as especially relevant for pupils who are hesitant to enter the creative processes of image making. By having access to new tools of visualising prefigurative thinking, more visualising processes can be materialised than if not. This harmonises with the results of Lyu et al. (2022), where the non-artist participants were excited by the possibility to create images that looked professional. AI text-to-image generators can also be used by those who are physically not able to use and master traditional forms and techniques of visualising, which mean that AI can allow for greater inclusion in visualising learning activities. Artificial intelligence text-to-image visualising can also allow for imagery which might not be possible at all or on the borders of or outside the parameters of skill. This imagery can include impossible situations or complex emotional expressions which can be hard to portray. An example of this is shown in Figure 3.1, where the intention was to show a person in a state of despair and rage on the border of crying. Producing this image with conventional photography would probably need a model or actor and a photographer at a very high skill level. This can open new possibilities of visualising outside the real. In other attempts we explored impossible combinations, such as in Figure 3.2, an iteration of a 1910 archaeological dig of an ancient robot.

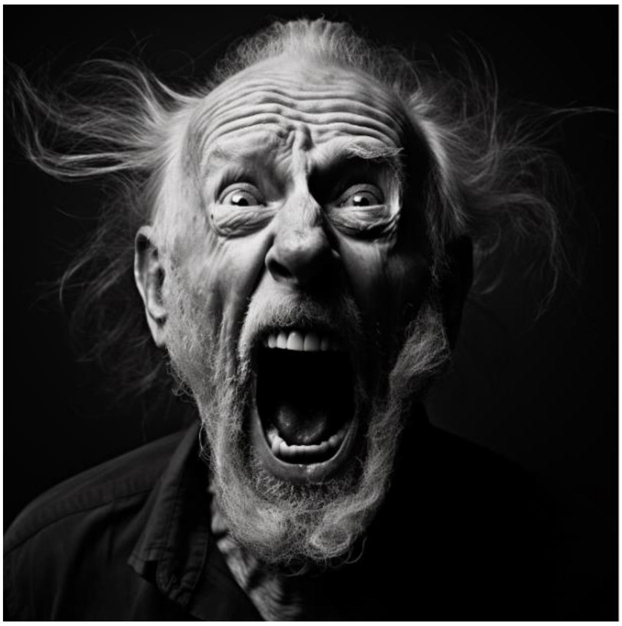

Figure 3.1 (left) and 3.2 (right). Generating emotionally complex or impossible imagery.

An online arena for sharing and collaborative creativity

Midjourney and Discord provide an arena for knowledge-sharing and collaborative generative art and design processes. These processes take place via a variety of chatrooms, show-and-tell rooms and other channels of communication. In these multi-human and machine collaborations, several users and the AI generative technology are part of discussions. Through discussions and testing, they collaborate on developing prompts, aesthetic qualities, and designs. This online space for potential collaboration and co-learning provides a learning environment independent of place. Figures 4.1, 4.2, 4.3 and 4.4 provide examples of Midjourney users collaborating and helping each other to achieve a desired image. Collaboration and seeking guidance from others through sharing is an important part of creative professional work and are also highlighted in new curricula in primary and secondary education (Norwegian Directorate for Education and Training, 2020).

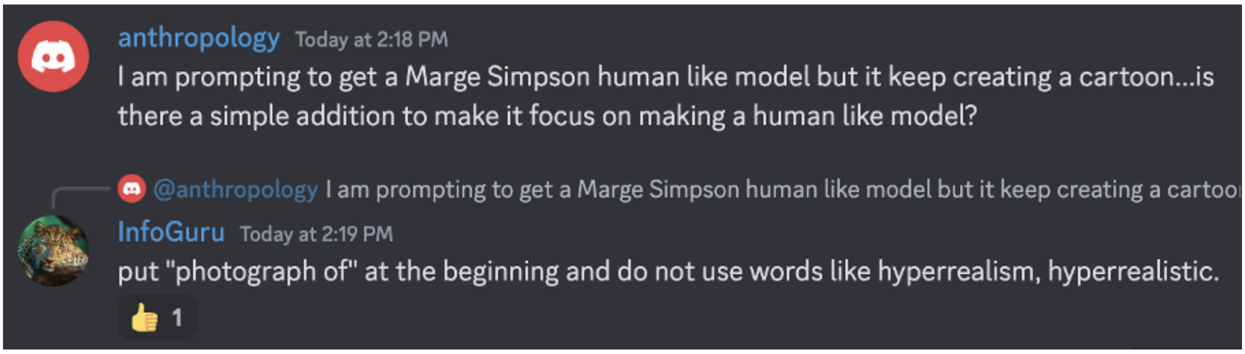

Figure 4.1. Requesting prompt help. Discord, Midjourney server, prompt-chat screenshot.

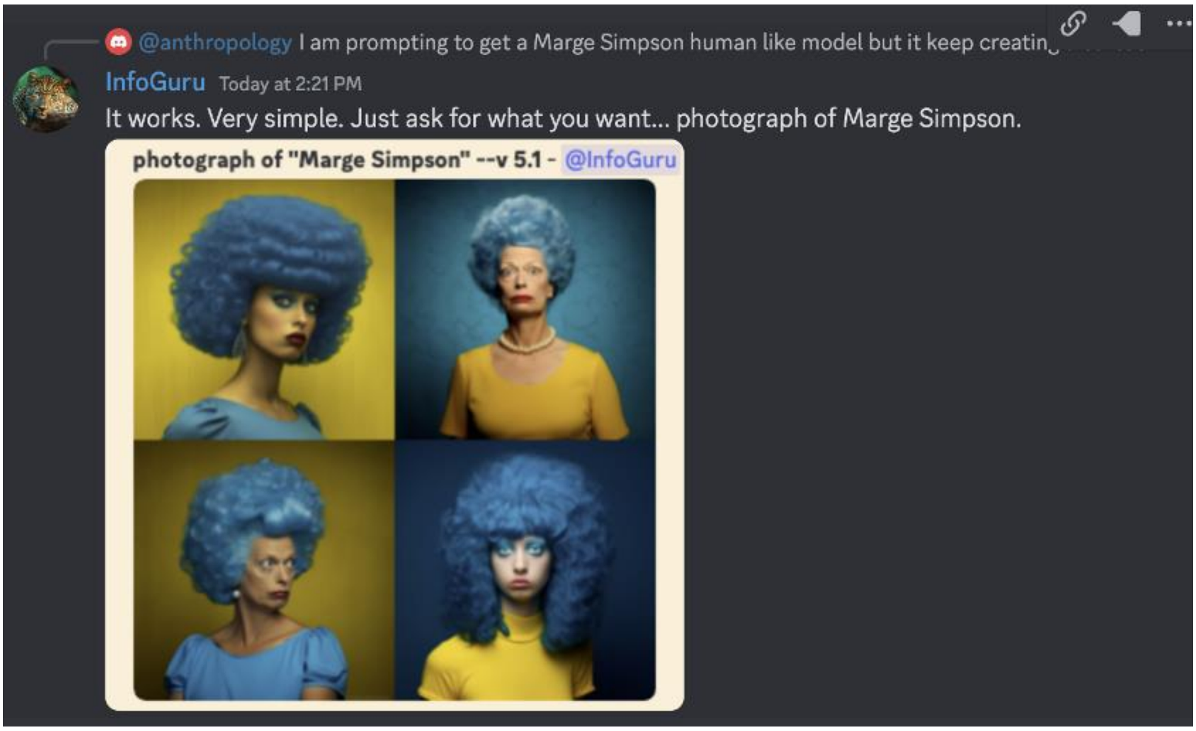

Figure 4.2. Help suggested. Discord, Midjourney server, prompt-chat screenshot.

Figure 4.3. Help suggested, follow-up. Discord, Midjourney server, prompt-chat screenshot.

Figure 4.4. A third user joins. Discord, Midjourney server, prompt-chat screenshot.

A visual aid for developing perspectives and composition

Artificial intelligence images can be useful visual aids for creative work. In our exploration, one of the authors tried this approach to draw compositions for a comic book, including an image of a large dragon sleeping in a parking house. Using AI generated images, he could explore how to draw this composition. Images created with Midjourney often do not meet the creator's expectations, but the images can be used as sublayers for reference in constructing illustrations. By prompting several iterations of a dragon and the environment and combining multiple images to get a reliable perspective (Figure 5), the drawing could be completed. In another case AI images were used as visual aid to draw a greeting card to a boy's confirmation, a traditionally Lutheran but now also a secular coming of age-ceremony. When prompting, the term 'coming of age' didn't produce anything useful, neither did 'confirmation'. Being more concrete, describing the desired motif, such as 'young man' or '15-year-old boy in a suit, standing next to' or 'leaning against a tree', did produce enough imagery to be used when making a hand drawn and water colour card (Figure 6). Other visual aids in this matter included architectural designs, different perspectival problems, light and shadows, body postures and anatomy studies. The final sketches and drawings were based on parts of AI generated images built upon various iterations in an interaction between articulating and implementing or aborting the results before articulating new prompts.

Figure 6. Imagery from the process of making a water colour greeting card.

Figure 5. Dragon and environment image generations combined with author’s own sketch work (far right), used for reference in creation process.

A multitude of idea generations

The study identified that, in creating object designs, the AI generated a multitude of varying idea visualisations. A series of relevant designs were easily created when the object shape was conventional, such as a ring (Figure 7.1), or a conventional object design such as a car or a toaster (Figure 7.2). The AI does not rethink a functional need or type of use but generates imagery based on convention if the name of the object is used in the prompt. In a search for new ways of thinking about object design, we have explored the use of more descriptive prompts, such as ‘a new and ground-breaking technological device that can warm up slices of bread in a distant future created with an unknown material’ (Figure 7.3). Another way of creating interesting results or suggestions useful for further explorations, are mashups of existing design visualisations. The variations are more decorative rather than shape variations.

In a creative learning process, students’ abilities to generate ideas differ. A common obstacle in the creative process can be a lack of variation of ideas in the early stages, leading to unsatisfactory results that do not fulfil their potential. The ease of generating idea visualisations can help prevent concept or design fixation (Schut et al., 2020), which is also demonstrated in previous research on AI in product design (Chen et al., 2019; Liu et al., 2019). Artificial intelligence text-to-image technology can provide new avenues for solutions to a problem or new ways of seeing and understanding.

Figure 7.1. Engineering department alumni ring design propositions.

Figure 7.2. Different toaster design propositions.

Figure 7.3. Toaster design propositions attempting to avoid the object design conventions.

Potluck visualisation as a tool for creativity

Artificial intelligence text-to-image generation can be a game of chance, providing surprising image results. This potential potluck quality of AI text-to-image generations led us to look at our initial ideas in new and unforeseen ways. Opening new avenues of thought can be rewarding in the creative process. While providing new possibilities, it also emphasises the need for a more critical creator role, as further described below. Using chance or coincidence in idea generation can contribute to new perspectives that enrich the creative process (Fazel & Almousa, 2021). Surprising image results, unrelated to the original idea, can be exciting to develop further. In these cases, the process, or 'dialogue' with the text-to-image generator, produces new and unexpected outcomes. This resonates with Oppenlaender (2022, p. 198), who has referred to unexpected results and serendipity, or two of the participants of Lyu et al. (2022) who likened the use of AI as opening Pandora's box.

The element of surprise has also a comical or amusing side to it which can be a social factor when it comes to learning. When prompting together in the classroom, students of both Year 6 and teacher education could be motivated by attempting combinations and aesthetic qualities that brought laughter to the group. This light-hearted side to prompting and text-to-image generation can benefit group dynamics which are valued in an educational setting. Humour can contribute to the learning environment in a positive way, helping the students in their willingness to focus on tasks (Banas et al, 2011).

Developing and strengthening a visual reference language

We identified articulation as an important stage between idea and prompting (Figure 1). The training of articulation from prefigurative thought to writing can contribute to the development and strengthening of a visual reference language. On the one hand, the ability to use the subjects' terminology is often highlighted in curricula (Norwegian Directorate for Education and Training, 2020). On the other hand, when articulating and writing prompts, one might use words or phrases not necessarily viewed as correct in the Art and design discipline. However, they work well when prompting due to their widespread use online, for example in gaming communities.

Novel users of text-to-image technology seems to differ in their ability to articulate and prompt accordingly to increasingly control the outcome of the generative process, based on our experiences from the workshops we have conducted. In one task we asked participants to prompt about their dream houses. Their backgrounds were diverse, ranging from advisors to teachers and students affiliated with various institutes and departments. There was also a variation in age and experience with digital technology. The outcomes from the prompts greatly varied. Some quickly understood that they had to adapt their prompt to express a different idea. However, others seemingly didn't comprehend that they had to describe what they wanted themselves. It appeared as if they thought the AI had intelligence, that it could understand what they meant. Much of this could be related to age - those with less experience and who are not as confident with digital technology, didn't quite grasp how it works. The Year 6 students, on the other hand, had a more intuitive understanding of the prompting, which they likened to chatting with a person. Those with more experience intuitively understood the task and adjusted their prompt accordingly. This concurs with Pennefather (2023) who highlights the importance of prompting multiple times: 'With little effort comes little result' (Pennefather, 2023, p. 206).

The 'concept-articulating catalyst wizard', a changing role of the image creator?

The study's exploration identified that the role of creator in creative processes using AI text-to-image technology differs from the creator's role in traditional image making such as drawing or painting. We see the creator's role shifting towards that of an art director, composer, editor, or selector. The process role of editing and catalysing black box processes consists of articulating, testing, developing, adapting, refining, selecting, and editing by starting new cyclic processes, as described in Figures 1 and 2. This shift in the creator's role questions what kind of knowledge and skills will be needed in future creative processes. With a shift towards editing and selecting rather than producing, a critical mindset should be an important part of future creator and design competencies. Such a mindset should be critical of results and open to different solutions of visualising prefigurative thoughts.

In this AI-assisted creative learning process, the idea and articulation stages can be seen as more important, compared to a traditional image making process, due to the ease of generating or producing. This added importance of imagining and articulating what you imagine highlights the need for a focus on prefigurative thinking and communication skills in future education.

Potential learning obstacles

In the following section, we will present and discuss the potential learning obstacles identified through our study.

Chasing the centaur, not getting what one wants

An example from our testing was to create a centaur by using different prompt-writing approaches. Whether writing a short prompt, such as 'centaur', or describing what a centaur is, the results were mainly images of horses. Other results depicted a man standing in front of a horse-like body, or a human torso attached to a horse's back (Figure 8.1). Although other Discord users in the Midjourney community had managed to create centaurs, a successful prompt copied and pasted from the community also elicited poor results. Other absurd combinations were also difficult to accomplish. The first attempts at creating AI images may be fascinating, but the wow factor will not necessarily last for long. Trying to create something based on ideas and imagination may lead to disappointing results that do not match how one visualised the ideas in the first place. The natural limitations of a given technology or tool will limit the possibilities.

Figure 8.1. A selection of the failed centaurs.

In an ongoing process with several iterations of different centaurs ending up as horses, figure 8.2 is the closest we got so far. This was partly based on tips found in relevant discussions from the community, where phrases like 'wearing four graceful horse legs' was helpful in generating centaurs instead of horses. Other useful phrases could be that the centaur was holding something, to indicate that it had arms. Writing 'wearing a helmet' could indicate a human head as opposed to a horse's head. This way of articulating gave us gradually better control over the results. Several results were abandoned, but parts of the prompts that gave somewhat satisfying results were reused in new combinations. In this way we redefined how we articulated, and results could be implemented in new iterations, or abandoned.

Figure 8.2. One of the most successful centaurs so far.

Bias and stereotypes

As the images generated by text prompts are based on image-and-text pairs from the internet, biases and stereotypes may be reproduced, which is also mentioned by Vartiainen and Tedre (2023). If ethnicity or gender was not specified in a prompt, a white male was often featured in the results in our early attempts unless the prompts contained words typically associated with woman. In 2024 Google's Gemini created images perhaps being too woke (Kleinman, 2024). Even if the biases are reduced, the datasets still need to be trained on classifications that put human beings into categories (Crawford, 2021).

In some attempts to see whether Midjourney made female or male superheroes, most results produced different versions of Superman in a style resembling acrylic paintings. With shorter prompts, Midjourney may create more surprising results, although one can recognise its default visual style (Pennefather, 2023). Often, digital illustrations of young women with long dark hair appear in the results based on short prompts, even if the prompt suggests content without any people in it, such as mood boards of a specific mood or hue of colour (Mikkonen, 2023). By prompting 'superhero' Midjourney may recreate image data connected to well-known superheroes in our popular culture. One way to avoid the typical *Midjourneysce* style can be to ask for photographs, or other artistic styles. Adding a year or an era in the prompt will also produce results with more variations, both in style and in motif. Asking for black and white photos of female superheroes in the 1890s (Figure 9, left) gave more gritty results than just prompting for female superheroes. Adding older, elderly or geriatric to the prompt can result in more grown up or middle-aged people (Figure 9, right). To avoid both biases and results that look too much like existing imagery, a more detailed prompt is therefore recommended.

Figure 9. Black and white photo of two female superheroes. Left: 1890s, right: geriatric.

Ethics, privacy, copyright, and censorship

Who owns images created with AI? Being trained on large datasets from the internet, there is no guarantee that images will not violate any copyrights (Abdallah & Estévez, 2023; Hutson et al. 2024, p. 32). In a classroom setting one can explore and experiment with images without violating copyrights (Bergman, 2021). However, as Midjourney shares the generated images with the community and the creator alike, one can question which copyrights are potentially violated with each image generation. Making images in an AI-based process provides a natural ground for discussing ethical dilemmas of copyright infringements and obstacles of censorship. Due to different types of censorship, some of the AI models have certain constraints. With Midjourney, one cannot create imagery based on prompts that suggest sexual content, while materials potentially violating copyright or personal data issues seem to be accepted. Compared to Midjourney (Figure 10), Adobe Firefly is more restrictive regarding copyright issues as also Hutson pointed out (2024, p. 111). These limitations in technology due to censorship, copyright or privacy issues limit the user’s freedom to express their prefigurative thoughts in visualisations.

Environmental issues need considering when using AI, like other internet-based technology such as cloud storage and search engines. The impact spans from mining minerals to coal driven energy consuming data centres and water consumption (Crawford, 2021). These issues are complex but in using AI generators one should be aware of the impact this has on the environment. AI generators are also dependent on human repetitive underpaid work such as training the datasets through labelling (Crawford, 2021, p. 63).

Figure 10. Prompting a realistic Mickey Mouse in Midjourney (left) and Adobe Firefly (right)

If AI text-to-image generation is to be used in schools, there are several considerations when it comes to navigating the complex terrain of copyright and privacy regulations. Elementary schools seldom allocate funds for platforms shielded by paywalls. While numerous non-payment AI tools exist, our experience indicates these often lack the comprehensive filters found in their paid counterparts. For instance, unintentional generation of images with sexual references. The non-payment generator Krea generated close to pornographic images to the innocent prompt ‘sunset on a beach’. Privacy concerns also arise when uploading images that might jeopardize personal privacy, such as faces or other identifiable data. This not only opens the door to potential digital bullying but also highlights the critical importance of privacy awareness. There have been incidents where students use AI-tools to make fake, realistic, pornographic images of other students (Jargon, 2023). This deep-fake technology has rapidly advanced in the last years, making it possible to create highly realistic media content that convincingly mimics the appearances of individuals. This technology carries the potential for abuse, including the spread of false information and digital depiction of users (Karnouskos, 2020; Pennefather, 2023).

Non-payment AI tools tend to feature a considerable amount of advertising. Educational institutions are prohibited from exposing students to advertisements in class. To bypass these ads, users often need to register or subscribe, which requires personal information such as an email address. Should a student be required to disclose such information, school administrators must adhere to strict privacy regulations. Without proper agreements between the school and the data processor, the risk associated with privacy becomes considerably high. If not properly safeguarded, personal information pertaining to students and teachers could be exploited, leading to potential exposure to various risks. Our exploration has revealed that AI tools behind paywalls generally offer superior image resolution, more effective copyright and privacy filters, absence of advertisements, and faster image generation. It presents a valuable opportunity to reflect on the importance and nuances of these matters in the digital age educational setting.

A cop-out?

The low-effort ease of image making with AI makes us question whether its extensive use can result in a non-critical view on the benefits of making. If the use of AI text-to-image technology replaces sensorimotor making activities such as drawing, what is possibly lost in a creation process consisting less of producing and more of articulating and selecting? Training is essential in traditional image-making processes consisting of applying sensorimotor techniques. Drawing skills are developed over multiple years of practice. If such sensorimotor skills for producing imagery based on prefigurative thinking become superfluous, what is the incentive in education to develop sensorimotor skills for mimetic drawing, as described by Nielsen (2013)? Is this ease of use a hindrance to learn or can it possibly free up more time to focus on other knowledges and skills necessary in a future learning environment? The use of AI technology in learning processes demands a critical teaching mindset, ensuring the necessary training and development of the skills needed.

Concluding remarks

This has been an initial study aiming to explore the use of AI text-to-image generators in a broad fashion. The study has identified several possible avenues for further research, such as how the potentials of the technology can be used in K-12 arts education. This include how AI text-to-image generators can stimulate the pupils' creative processes or how generated images can be combined with traditional crafts. However, with the widespread use and development of this technology, we emphasize the need for a critical perspective in future research.

Artificial intelligence text-to-image technology can contribute to and change future Art and design education in various ways. It can contribute to increased opportunities for training prefigurative thinking, providing new ways of visualising and co-creating. This can represent a democratisation of visualising prefigurative thinking, as creators are not being restricted by their limitations in skills or techniques. The use of AI can simplify and enrich image making, design and creative processes. Artificial intelligence text-to-image technology can represent a useful tool for creative processes and developing articulation for visualising the imaginary. Its use can also represent limitations to creativity and contribute to ethical questions and issues of bias being raised. With the application and use of AI text-to-image technology in art and design education spreading, we need to question what kinds of competencies are needed in future learning processes.

AI text-to-image generated image copyright statement by authors

All AI text-to-image generated images in this article were created using Midjourney, except one image using Adobe Firefly (Figure 10). To create images with Midjourney you will need a subscription plan. According to Midjourney's content rights, the creator of the images owns all created assets (Midjourney, n.d.-c.).

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29.2

Comparing Augmented Reality in industry and Technology Education: Exploring teacher views and research needs

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Abstract
The use of Augmented Reality (AR) is a relatively new but significant trend in the educational landscape, including in technology education. The aim of this article is to discuss different perspectives on AR applications and describe the similarities, possibilities, and differences between them. Initial research in the field of technology education has shown numerous applications, especially since many tools, machines, and techniques must be learned in the hands-on practical sector, a discipline where AR is already being used in the industrial sector. However, there are even more applications in the industrial context. The resources utilized in these cases are often not available in the education sector, and the requirements for such systems differ between educational and industrial applications. When considering the specific application of AR in schools, it offers yet another perspective compared to educational research and industrial applications. Based on the results of an exploratory study among technology teachers in Lower Saxony, it becomes clear that costs, accessibility, and the lack (thus far) of appropriate learning materials are seen by teachers as the biggest challenges to effectively using AR in schools. It is noted that research and development projects in general technology education are necessary to effectively implement AR in technology education.

Keywords
Augmented Reality (AR), Technology Education, Educational Research

Introduction
In this article, the technical foundations of Augmented Reality, including a comparison with Virtual Reality (VR), are first discussed. This is followed by an examination of the use and research in this field from the perspective of industrial applications and education. The latter is presented both through the literature and a recent exploratory study among teachers in Lower Saxony. In a final discussion, these various perspectives are compared and analysed.

Augmented Reality
The terms VR and AR have become commonplace in everyday language, partly due to the gaming industry. However, the origins of these terms and technologies date back not to the 21st century, but to the late 1960s, with Sutherland's work in 1968 (Adelmann, 2020; Dörner et al., 2019). Various definitions of AR are found in the relevant literature, often referencing the definitions (or definition approaches) by Azuma (1997) and Milgram and Kishino (1994) (Mehler-Bicher, Steiger, 2022; Dörner et al., 2019; Adelmann, 2020; Hamann et al., 2020). While Milgram and Kishino categorize the term within the MR taxonomy (Milgram & Kishino, 1994; Milgram et al., 1994), Azuma stipulates conditions that must apply for AR (Azuma, 1997).

Figure 1 shows the Reality-Virtuality Continuum by Milgram and Kishino. The MR taxonomy indicates that the terms Augmented Reality, Virtual Reality, and Mixed Reality should not be considered synonyms; rather, there is a factual distinction between them. The specific overlay case that applies depends on the degree of virtual overlay. Thus, the continuum postulates a continuous transition between real and virtual environments (Mehler-Bicher, 2022). The continuum is bounded by two extremes. One extreme is reality, which describes the physical real objects and aspects captured by a medium or perceived in a real setting (Milgram & Kishino, 1994). The other extreme is virtuality, consisting solely of virtual objects (Milgram & Kishino, 1994). Between these extremes lies Mixed Reality, describing environments composed of both real and virtual elements. Depending on the degree of overlay or intensity of mixing of these environments, either Augmented Reality or Augmented Virtuality (AV) is present. MR describes both states, while AR is present only when the real component predominates within the environment. Thus, every AR environment is also MR, but not every MR is AR (Milgram & Kishino, 1994).

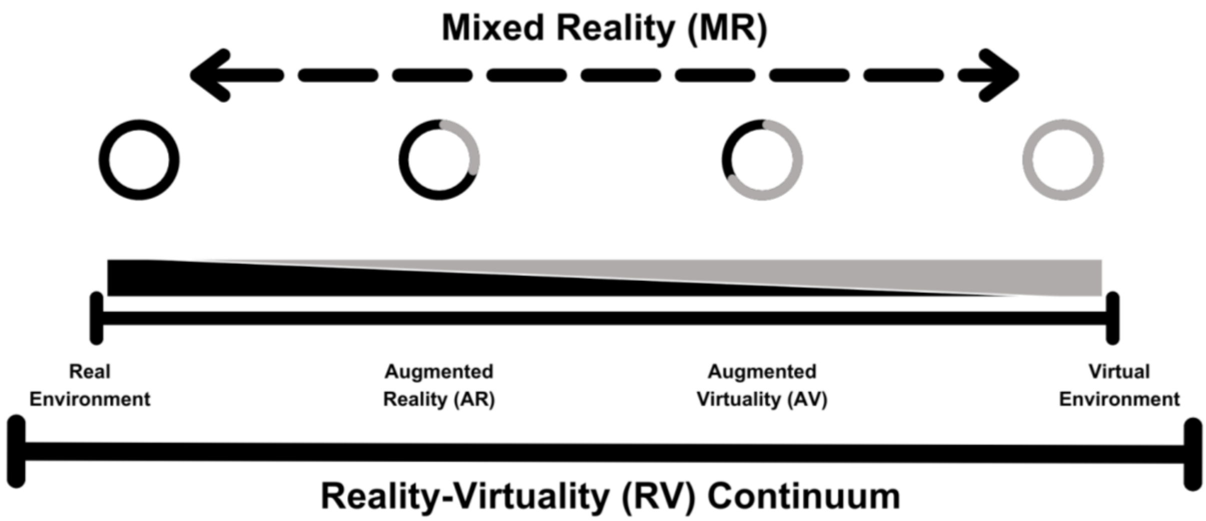

Figure 1. The Reality-Virtuality Coninuum own illustration based on Milgran et al. 1994, S.283

Azuma (1997) clarifies his AR postulate in his definition approach by identifying three main characteristics. Accordingly, an environment is identified as AR when there is a simultaneous existence of real and virtual environments with partial overlay, real-time interaction, and a three-dimensional relationship between virtual and real objects (Azuma, 1997). In popular science, AR is often merely limited to the enhancement of reality with virtual content. This limitation considers AR only in a broader sense; in a narrower sense, an environment can only be identified as AR if all of Azuma's main characteristics are present (Mehler-Bicher, 2022).

Wiemer and Rothe (2022, 2023) and Wiemer et al. (2024) discuss in the context of teaching-learning situations that there are two instructional dimensions for AR. On one hand, there is learning with AR, which activates learners through an AR environment to stimulate their own learning processes, and on the other, there is learning through AR, which explicitly involves learners in creating AR content. By doing so, learners not only build knowledge but also enhance their creativity and skills in AR technologies (Wiemer & Rothe, 2022, 2023; Wiemer et al., 2024).

It was already emphasized at the outset that the terms VR, AR, and MR are now present, although their origin dates back to the late 1960s. The appearance that these are new technologies can be attributed to the fact that these technologies have rapidly gained significance in industrial practice. This can be attributed to fundamental changes, such as massive advances in hardware for these technologies, matured ecosystems for developing solutions, and numerous synergies for VR, AR, IoT, and Machine Learning (ML), which mutually drive each other forward (Adelmann, 2020).

Applications of Augmented Reality in the Industrial Context

In the previous chapter, it was shown that AR is not a new invention but has gained increased relevance in industrial practice due to technological advancements (Adelmann, 2020). This development is characterized by improvements in hardware, software, and the integration with other technologies such as IoT and ML. Mobile technologies have significantly contributed to advancements in AR-relevant technology areas such as sensors, display technologies, wireless transmission, and battery performance. Microsoft's HoloLens is cited as an example of modern AR hardware, which, despite a limited field of view, is considered pioneering for the development of further improved head-mounted displays (Adelmann, 2020). Development environments like Unity3D, which simplify the creation of AR content, are also highlighted.

General Development

The significance of mobile AR, enabled by technologies like Apple's ARKit and Google's ARCore, is notable. These technologies have made AR accessible to a broad audience and laid the foundation for industrial applications (Adelmann, 2020). By utilizing existing development platforms and tools, AR applications can be developed efficiently and cost-effectively, promoting their use in the industry. Furthermore, synergies between AR and other technological developments such as VR, ML, and IoT/Industry 4.0 are discussed. These connections enable new use cases and foster innovations in their respective areas. The integration of Machine Learning, for example, enhances interaction with the real world in AR applications through robust recognition capabilities for speech, text, gestures, and objects (Adelmann, 2020). These points illustrate that the combination of technological advancements, integration with other technologies, and the development of more accessible tools increasingly make AR practical for industrial use. AR can enhance human-machine interaction and increase efficiency in production and maintenance, opening new perspectives for the industry (Adelmann, 2020).

Fields of Application

In the manufacturing industry, AR is used to enhance traditional production processes by integrating digital information into the user's field of view. AR can enable workers to see relevant data and graphical instructions over their real environment, which is particularly helpful in complex assembly tasks. This technology can help reduce errors, increase safety, and accelerate the training of new employees. AR can also facilitate the maintenance and monitoring of machines by visually presenting condition information and performance data (Dhanalakshmi et al., 2021).

AR can play a role in improving safety and efficiency in manufacturing processes. By displaying safety warnings and operating instructions directly in front of employees' eyes, accidents can be prevented, and work efficiency can be increased. AR technology can also be used to visualize complex components and assembly processes, which is particularly advantageous in the production of high-quality or critical components. AR enables interactive and dynamic adjustment of production processes in real-time, based on current operating conditions and requirements (Dhanalakshmi et al., 2021). In the context of Augmented Reality Aided Manufacturing (ARAM), AR is used to improve assembly accuracy and production efficiency. ARAM includes technologies that display work instructions and critical information about components and assembly steps directly in the workers' field of view, reducing the need to consult traditional construction plans or instructions. This directly embedded information helps minimize errors and ensure the quality of the final products (Dhanalakshmi et al., 2021).

The implementation of AR in manufacturing involves various technologies such as marker-based and markerless AR. Marker-based systems use visual markers to position information precisely, while markerless systems often use GPS and sensors to determine positioning. These capabilities can be used for a variety of applications, including for planning factory layouts, where digital planning data is transferred to real environments, allowing for more accurate planning and implementation. Moreover, this can be used to plan and simulate manufacturing processes, as well as to monitor production lines and perform safety checks. AR is also used for training and further education of employees by illustrating complex processes and providing interactive learning experiences (Dhanalakshmi et al., 2021). The combination of AR with VR offers additional opportunities, for instance, overlaying virtual prototypes with additional AR information. This can accelerate product development while simultaneously reducing the costs of physical prototypes. AR supports VR applications by providing contextual data that facilitate interaction with virtual environments and improve accuracy. This synergy allows for a more seamless integration of design, testing, and production, which is particularly beneficial in high-tech industries (Dhanalakshmi et al., 2021).

Potential

Sharma et al (2024) show that AR offers potential for automated driving. In a literature analysis, they show that AR can connect driving and road safety. Real-time data, intuitive route guidance and more advanced safety practices make driving more productive. At the same time, however, they also emphasise that there are risks and hurdles, such as information management and security, that need to be overcome (Sharma et al., 2024).

Rysbek et al. (2024), on the other hand, analyse an AR client with regard to its suitability for implementation in additive manufacturing. They implement an AR client in the manufacturing process of a 3D printer. The results show that the proposed client enables bidirectional communication between the 3D printer and AR client. The client makes it possible to see and operate the 3D printer software interface in a HoloLens2 (Rysbek et al., 2024).

Research and Development

AR is already being used in various ways in the industrial sector, although the mentioned application areas show that much research and experimentation is still ongoing, and some areas of application have not yet moved beyond the project stage. Research in the AR field focuses on further development of the technology, improving user experience, and opening up new application areas. A focus is on the development of more powerful and user-friendly AR glasses that offer longer battery life and better image quality. Additionally, researchers are working on improving interaction possibilities with AR applications through advanced gesture control and speech recognition. A summary of the usage potentials according to the Fraunhofer Institute for Design Technology Mechatronics (Fraunhofer IEM, 2024) describes the following application possibilities:

- Context-specific visual support for activities, e.g., in maintenance and servicing;
- Time savings, e.g., by eliminating the need for time-consuming information searches by technicians;
- Cost savings, e.g., by reducing training efforts and the elimination of paper-based documentation;
- Quality improvement, e.g., through visual inspection of work steps;
- Global availability of experts, e.g., through AR-based remote systems;

It is interesting to note in the overall view of AR application areas in the industrial context that many of the mentioned points can be prescribed in an extended learning area. Examples include information search, reduction of training efforts, and control of work. These are also points that could be relevant in the use of technology education. The same applies to the use of increasing safety or for simulating processes that would otherwise not be representable. Less relevant are areas like factory planning and the optimization of assembly efficiency, as these are less relevant in school education, which usually aims to gain initial experiences with technology.

Applications and Research in Augmented Reality within the Educational Context

As the previous chapter demonstrates, the fields of application for Augmented Reality (AR) in the industrial context are expanding, and correspondingly, AR is being increasingly researched. There are also various applications in the educational context, with a significant body of research in both the specific area of technology Education and in the educational context more broadly.

Academic Achievement through AR

In conceptualizing the learning outcomes of AR/VR applications, Schweiger et al. (2022) refer to two theoretical models that outline learning success from different perspectives, thus synthesizing the current state of research in the field of learning outcomes through AR. To capture learning outcomes from a technology context, they employ the SAMR Model by Puentedura (2010), while learning outcomes from an educational context are assessed using Schlicht's Structural Model (2014). The SAMR Model illustrates how digital technologies can be used to enhance learning methods. On the other hand, the Structural Model views learning as a multidimensional phenomenon consisting of five levels. While the levels of knowledge, skills, and abilities describe actions linked with cognition, sensorimotor skills, metacognition, and social processes, motivation describes emotions in relation to will or intent and the emotional process of action adjustment. The fifth level, attitude, represents a lasting object- and situation-specific value orientation concerning personal goals and motives (Schlicht, 2014).

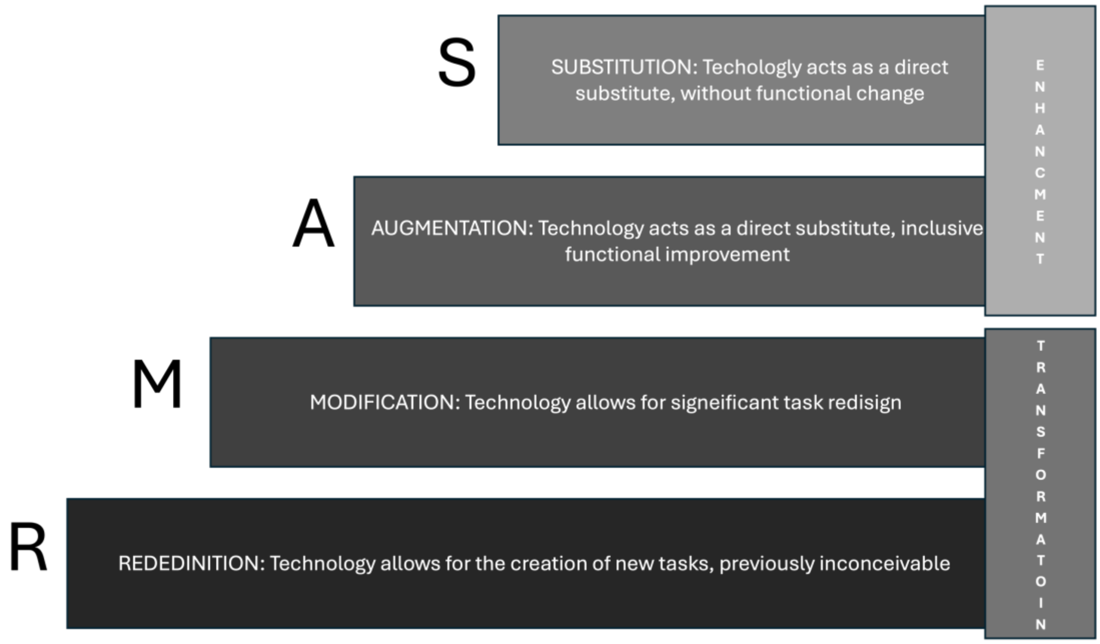

Figure 2. SAMR Model own illustration based on Puentedura (2010).

From the examination considering both the SAMR and Structural models, four contexts of learning success through AR/VR were identified. The first context is the technology context, which, according to the SAMR, can be divided into Substitution, Augmentation, Modification, or Redefinition. The media most commonly substituted by AR/VR are textbooks (n=20) and worksheets (n=13). Almost all studies (n=28) demonstrate that AR/VR introduces a functional extension of learning by visualizing and scaling abstract learning objects. Regarding Modification, it becomes clear that two important aspects of redesigning and enhancing learning processes can be observed. For example, the combination of AR/VR applications with existing media output devices holds potential for creating immersive learning environments with digital and game-based learning concepts. Another aspect is that learners, through the implementation of immersive learning environments, can themselves determine the pace and duration of learning. Immersive learning environments also create new learning opportunities (n=8). Learners can use AR/VR technologies to learn asynchronously, explore virtual learning spaces individually (n=21), or learn at home using the Flipped Classroom model (n=13) (Schweiger et al., 2022).

Regarding the Structural Model, learning success in the educational context was also noted. For instance, procedural knowledge about methods and techniques or problem-solving strategies is enhanced in school settings through immersive learning environments (n=27). Declarative knowledge about terms, conditions, and events is also supported (n=23). In terms of skills, AR/VR technologies can enhance the perception of multisensory abilities through novel visual, auditory, and sometimes tactile stimuli (n=18). Learners' own stock of knowledge (n=20) through reflection on what is learned after using immersive learning environments and collaborative learning through AR technologies (synchronous n=16, asynchronous/online n=20) can be fostered. The mere use of immersive learning environments is already seen as a motivational factor (n=11). The acceptance of technology and learners' attitudes towards AR/VR technologies as learning objects are consistently viewed positively (n=25). In terms of media literacy, Schweiger et al. observe that the primary focus of investigations in the school context is mostly on reception and impact, rather than on learners' own creation of AR/VR applications (n=25) (Schweiger et al., 2022).

Other contexts of learning success include temporal and psychological contexts. Scientific studies predominantly indicate short-term effects since the investigations are gathered through observations or interviews immediately after the use. Research by Southgate (2019) concerning VR usage shows that learners can remember the learned content better in the long term.

Similarly, Wiemer et al (2024) show that the long-term use of AR technologies must first establish itself in daily use before long-term success can be attested. Psychologically, it is noteworthy that predominantly cognitive effects are identified (n=29). However, this can also be explained by the fact that the search criterion of the review study was learning success (Schweiger et al. 2022). The results of the study show that AR/VR technologies are already being investigated in the school context, with it being clear that, in particular, learning with AR as classified by Wiemer and Rothe (2022, 2023) and Wiemer et al (2024) is being investigated. This is not surprising considering that the technologies must first be examined regarding their suitability before it can be considered how students can create their own environments. Thus, it is shown that handling the technologies promotes acceptance of the technology. With growing acceptance and media competence in handling the technology, it is easier for learners to also consider the other side of the technology and thus focus on learning through AR.

Selected Examples

An example of learning through AR being applied is shown by Rigling et al. (2024). Within the framework of the project digit@L, students developed their own AR/VR environments, which are supposed to contribute to students building knowledge and skills for creating technology-based experiential worlds (Rigling et al., 2024). As an example, the authors cite an AR application designed by students. The AR application was developed by students of technology pedagogy. The content focus was on the disassembly of a gearbox. Thus, the students created an AR-based disassembly plan for a gearbox by creating the CAD files of the gearbox themselves and integrating them into the AR application Jigspace. A detailed disassembly plan was developed in six steps, which should contribute to learners' reasoned creation of a disassembly plan for the gearbox (Rigling et al., 2024). Rigling et al. (2024) show, albeit exploratively, that by creating immersive learning environments, students develop situational interest in technology-based experiential worlds (Rigling et al. 2024). The learning process of technology acceptance regarding immersive applications is thus stimulated both by learning with and by learning through AR.

Overall, Rigling et al. (2024) state that students acquire the handling and acceptance of the technology through the creation. We would like to go further at this point and make assumptions that are not mentioned in Rigling et al. (2024). Looking at this scenario, this simple AR application can be considered in several ways. For example, the students develop an environment for learners. The learners who use the AR application for disassembly are therefore in the "learning with AR" aspect. The learning success and the competences that can be acquired through this have already been shown in Schweiger et al (2022). As Rigling et al. (2024) exploratively describe the students who have built the AR environment develop competences in the area of dealing with and accepting the technology. Accordingly, they are in the aspect of learning through AR. At this point, we would like to add another aspect and make the assumption that the students have also developed competences and expertise with regard to the content itself by creating the digital disassembly. The creation of an AR environment can of course also be understood as a teaching-learning strategy, similar to creating your own tutorials (Wolf, 2015; Ebner & Schön, 2017). In this way, the concept of learners developing their own tutorials promotes a deeper penetration of the content to be explained, as it is necessary to understand how the principle to be explained works (Wolf, 2015). We see it similarly when creating an AR environment that is intended to stimulate learning. We assume at this point, even if it certainly still needs to be investigated, that the students who created the disassembly plan have penetrated the gearbox in its overall complexity before they were able to prepare the AR content accordingly. Learning through AR would also work in this way.

Furthermore, AR allows practical experience with technologies and equipment that would otherwise be inaccessible for cost reasons or due to safety concerns. Through the simulation of real applications, students can gain valuable practical experience without the real risks. Regarding professional competence, Heindl and Pittich (2024) cite the virtual welding training room by Weldplus as an example. There, trainees use equipment (AR headset, controller) modeled after real welding equipment (visor, burner) (Heindl & Pittich, 2024). The AR simulation prepares for working with real welding devices, thus minimizing the risk potential (Prange, 2021).

Additional Perspectives

In addition to specific industrial applications, AR also offers significant opportunities for general technical education. Müller and Kruse, for example, show that 73.5% of all AR technologies are used in the educational context in higher education, although strictly speaking this remains at the level of learning with AR (Müller & Kruse, 2022). Furthermore, they show that the area of application of AR in the teaching/learning context is dominated by the natural sciences at 49.2% (Müller & Kruse, 2022). One example is the use of AR for the plastics industry and microplastics (Krug et al., 2022). AR technology is used to make the material properties tangible and to encourage collaborative work (Müller & Kruse, 2022). By using AR, teachers can convey complex concepts and processes in a vivid and interactive way. For example, students can view and manipulate virtual machines or systems in the real environment of the classroom, which promotes a deeper understanding of and interest in technical disciplines. The most common topics emphasised by Müller and Kruse in their systematic review are electrical engineering and technical drawing (Müller & Kruse, 2022). This seems logical in principle, as the complex world of electrical engineering in particular can stimulate other approaches through an AR application. Wiemer and Rothe (2022) showed in a study of the support needs of technology students that electrical engineering is one of the fields with the greatest need for support. Müller and Kruse also show that 61.8% of the studies identified use AR within a didactic framework in the teaching/learning context. Of these, 23.5% are virtual aids. A clear prioritisation of mobile (47.1%) or stationary (52.9%) AR solutions could not be determined (54). In 47.1% of the studies, the focus of the AR application is on the successful transfer of knowledge, while 32.4% aim to improve spatial awareness. In contrast, 14.7% investigated the change in work performance through the use of AR technologies (Müller & Kruse, 2022).

In summary, it can be said that the topic of AR technology education, as well as in education more broadly, is indispensable. Furthermore, there is a high level of research interest in learning outcomes, which seems logical in the educational context. The fact that much research is still conducted with students is also a sign that there is still a significant need for research and development, as these studies in the educational context usually take place before research is conducted in schools.

The Perspectives of General Technology Education Teachers on the Use of Augmented Reality in the Classroom

The Technology Education Working Group at the University of Oldenburg annually hosts a professional development day for teachers from Lower Saxony in the field of General Technology Education. Here, they can attend various workshops to further their professional skills. In 2023, the theme of the professional development day was future technologies, offering trainings in Maker Education, Robotics, and Augmented Reality. About 40 teachers participated in total.

As part of the augmented reality workshop, a system already in use at the university was first presented. The technical principles, conditions of use and possible applications of AR in the field of general technical education were then discussed. The teachers were also familiarised with the basics of the programme using an exact example. This served to demystify AR technology and familiarise the teachers with the low-threshold nature of the programme. There was also a forum in which further possible applications and difficulties with implementation were discussed. This served to encourage teachers to actively think about implementing AR in their school context. Eighteen teachers took part in this workshop as part of the training day**.** Following the workshop, the participating teachers were asked whether they already use augmented reality in their lessons and in what form. The survey also asked about the obstacles and problems that currently hinder its use. The aim of the survey was to generate initial indicators for future research and development perspectives, so it was an exploratory study (Stein, 2014).

Methodological Framework

A semi-open questionnaire was chosen as the methodological tool for the survey. The use of such a questionnaire is methodologically advantageous for several reasons. First, the semi-open questionnaire allows for flexible data collection, providing both standardized, comparable data through closed questions and deeper insights into personal attitudes and experiences through open questions. Second, the semi-open approach supports hypothesis development in exploring a new field, which can later be tested with quantitative methods. Finally, this questionnaire approach allows for high adaptability and responsiveness to the respondents' answers, especially when the research field is still so open and new (Bortz & Döring , 2002).

The questionnaire consisted of four questions, two of which focused on actual usage and therefore used a closed response format. Additionally, the questionnaire included a semi-open question on the reasons for not using AR and an open question on the challenges of using AR. All the teachers who participated in the workshop also took part in the survey, so n=18, although one teacher did not provide an answer to one question. The analysis was carried out using descriptive statistics to provide a summary and clear presentation due to the exploratory research design (generating initial indicators for research perspectives) (Bortz & Döring, 2002), and simple content analysis methods were used for the open questions to interpretively discern meaning structures in the answers (Reinders et al. 2015).

Results

The data analysis (Figure 3) revealed that, to date, only two of the 18 surveyed teachers have implemented Augmented Reality in their teaching. Accordingly, only these two could specify how they use AR. Here, they could choose between "theoretical", "practical", or both in a closed response format.

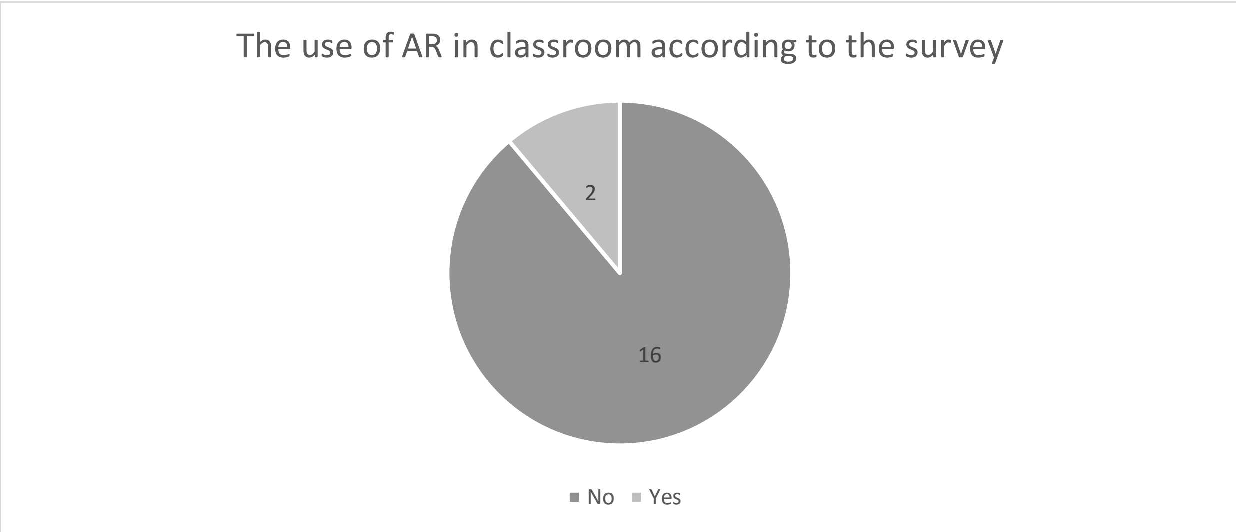

Figure 3. The use of AR in classroom according to the survey (n=18).

In another question with a closed response format and the option to add personal points, the teachers were asked why they currently do not use AR in their teaching. This question also allowed for multiple answers, as it was assumed that several reasons might simultaneously play a role. The n for this question was 17, as one teacher did not provide an answer.

The results (Figure 4) show that the curriculum and the facilities are least cited as reasons for not using AR, with only one or two mentions each. Lack of familiarity with the topic and no time for training were each mentioned five times, while the absence of appropriate teaching materials was mentioned six times. The most common reason given was "Too expensive to acquire and maintain," cited by eight of the 18 surveyed teachers. One teacher, who mentioned their own reasons, described the subject as too complicated for their target group and indicated they work in special education.

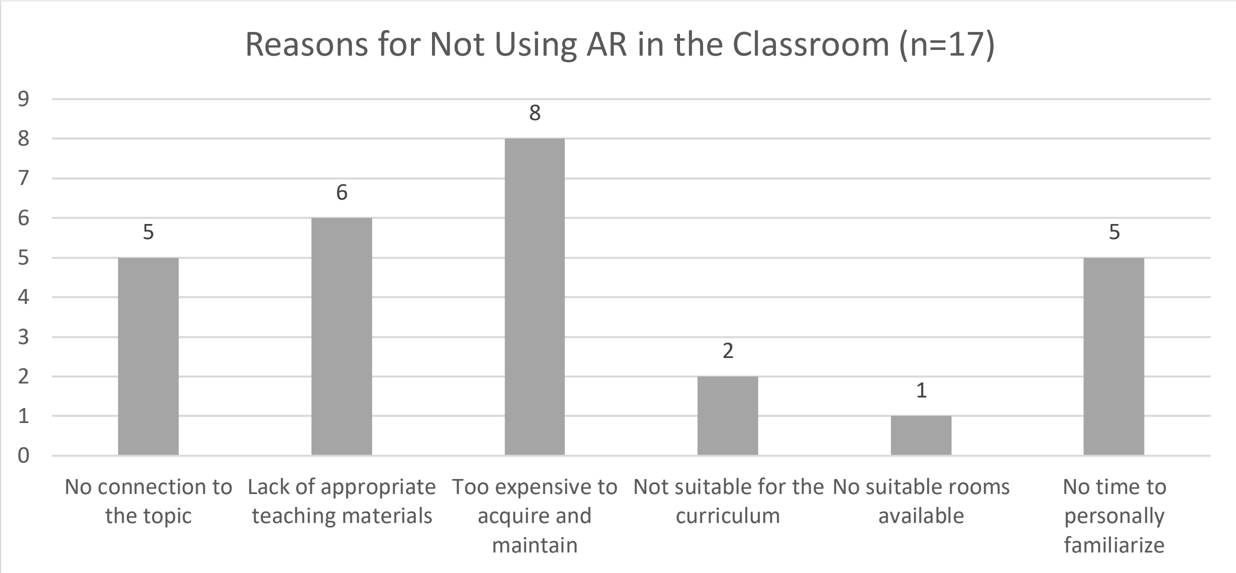

Figure 4. Reasons for Not Using AR in the Classroom (n=17).

The final question of the questionnaire related to challenges posed by Augmented Reality in technology education and was posed in an open format. The aim of this question was to gain a broad overview of the topic from the teachers' perspectives. The points mentioned could be categorized into several main categories: costs and resources, technology and subject-specific competencies, software and its handling, and didactic considerations:

1. Costs and Resources: Several comments referred to the financial and time expenditures associated with the introduction and use of AR in the classroom. It is clear that the costs for software and the necessary hardware (tablets, smartphones) are seen as significant barriers. Additionally, the cost-benefit ratio is questioned.
2. Technology and Subject-Specific Competencies: Basic knowledge is deemed necessary, and there are concerns about the complexity of the programs and the ability of the teaching staff to familiarize themselves with the new technology.
3. Software and Handling: Comments highlight that the existing software is perceived as too expensive, complex, and cumbersome to learn. The need for educational licenses and intuitive usability is emphasized, pointing to the importance of user-friendliness for successful integration into everyday school life.
4. Didactic Considerations: Some remarks reflect the concern that AR might be used for its own sake, without making a meaningful contribution to the learning process. The necessity to create meaningful and timely applications that are tailored to the age and abilities of the students is stressed.

The recurring themes of costs and handling complexity suggest that the teachers perceive a gap between the available AR technology and the practical realities of the school environment. Overall, the data reflect a picture of skepticism among teachers, coupled with a desire for more accessible and user-friendly solutions to implement AR meaningfully in the classroom. The latter indicates that the skepticism is fueled by perceived lack of solutions from the teachers' perspective, not as a fundamental rejection of new technology. In addition, it is crucial to establish long-term support structures for teachers to ensure they are able to continuously develop their skills in using AR technologies. Ongoing professional development and collaboration between schools and technology providers could help bridge the current gap between the availability of AR tools and their practical application in the classroom.

Discussion

The study reveals significant hurdles in the implementation of AR in the educational sector. The surveyed teachers see costs and technical complexity as particular challenges. Future research and (educational) development projects in the use of AR in technology Education could focus on developing cost-effective and user-friendly AR applications specifically designed for educational purposes and pedagogically linked with appropriate teaching materials. Another field of research emerges in the development and evaluation of learning settings that integrate AR, as well as in the area of teacher training for the necessary technology competencies. Another important research area could be the didactic potentials of this technology.

Conclusion

The use of Augmented Reality (AR) has made significant progress in both industry and education, showing great potential. In industrial applications, AR enables the efficient execution of complex tasks by allowing users to integrate information directly into their field of view, increasing productivity and reducing errors. These advances have been driven by improvements in hardware and the integration of key technologies such as IoT and machine learning.

However, in the educational sector, particularly in technology education, several obstacles still hinder the widespread implementation of AR. These challenges include cost, accessibility to necessary technologies, and a lack of adapted teaching materials. As a result, it is difficult for educational institutions to fully utilize AR as a teaching tool. Although teachers recognize AR's potential to enhance engagement and improve the learning experience, they often lack the resources and technical expertise for effective integration into the curriculum. To ensure the long-term integration of AR in technology education, continuous support and training programs for teachers are essential. These programs would help overcome technical and financial barriers while fostering the gradual adoption and effective use of AR in daily teaching practices.

For this reason, targeted research in technology didactics is crucial. Future projects should focus on developing affordable, intuitive AR applications specifically designed for educational purposes. Equally important is the creation of teaching materials tailored to AR technologies. Furthermore, AR offers opportunities for more individualized learning experiences, allowing students to explore complex technical concepts at their own pace. This is particularly beneficial in technology education, where hands-on learning is key. Research in this area could also aim to develop empirically based methods to introduce teachers to the technology and expand their pedagogical skills. Moreover, collaboration with the education sector offers valuable insights for the AR industry by exposing it to the specific challenges of classroom implementation. This feedback loop can lead to the development of more adaptable and user-friendly AR solutions that benefit both education and other sectors.

Finally, partnerships between the education sector and the AR industry could accelerate the development of tailored, accessible AR tools. Such collaborations would also give schools access to advanced technologies and professional expertise, fostering innovation. These initiatives could bridge the gap between the current use of AR in schools and its enormous educational potential.

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Book Review

A review of HildaRuth Beaumont and Torben Steegs' Design and Technology in your School: Principles for Curriculum, Pedagogy and Assessment

Reviewed by Mark Norris, University of Sussex, UK

Introduction

Design and Technology in your School: Principles for Curriculum, Pedagogy and Assessment is a book resulting from the long-term collaboration between Dr HildaRuth Beaumont (formerly David Barlex) and Torben Steeg, whose excellent blog I highly commend (Beaumont and Steeg, 2024). The book sets out a vision for how and why a well-planned and assessed design and technology curriculum can make a unique and important contribution to secondary school curricula. The book aims firstly to establish the importance of the subject and identify a philosophy and pedagogy for the subject. It goes on to explore key issues at the heart of its delivery before suggesting a model for teachers and subject leads within the subject to reflect on their approaches to curriculum design, delivery and assessment.

The book is written in a readable and engaging style with chapters which introduce the key concepts and ideas in a thought-provoking way, inviting pauses for thought and including additional contributions from a range of lively contributions from guest contributors from the field of design education. The chapters include many relatable links to classroom practice, detailed references to supporting literature and research as well as questions for the reader and links to further reading.

Chapter 1 Justifying design and technology

Here the authors explore the unique contribution design and technology can make to a balanced school curriculum and identify four possible justifications for teaching the subject, specifically asking the question of the reader how they would justify the place of the subject to school leaders. The first justification is that preparation for work, arguing that the skills taught in the subject prepare those studying it for careers in design. They pose the question can we rely on this to justify our subject given that there are relatively few jobs as designers in the economy as a whole. Personal development is the second benefit outlined in the chapter. A further justification identified is that the subject helps to develop self-efficacy and problem-solving skills and, the authors call on the design and technology community to provide a clear and unified vision for the subject. They invite the reader to reflect on the benefits of teaching the historical and societal achievements and the impact of design on society under the justification heading of cultural transmission and preparation for citizenship. In the first of the book's "thought pieces" Dr Alison Hardy encourages teachers to consider how they justify the subject to students studying it and agrees with the argument that the subject's impact on community and society should be considered.

Chapter 2 Understanding design and technology

In the fascinating second chapter Beaumont and Steeg explore the philosophy of design and technology challenging us to consider how our values relate to the subject. In the second half of the chapter, they go on to establish their vision of what is disciplinary and substantive knowledge within the study of the subject. At the heart of the chapter and, I would argue the book itself, is a challenge to those involved in the teaching of the subject to consider their values related to technology and how this might impact their curriculum and their approach to teaching the subject. Andy Mitchell, Ex-Deputy CEAO of the Design and Technology Association, contributes a think piece in which he explores how values can be explored and design thinking through collaboration developed. He makes the case for the value of designing - without making something - a concept championed by Beaumont herself (Barlex, 2012) and a theme returned to later in the book.

Chapter 3 Important issues

The challenge to design and technology educators to consider their values within their practice and curriculum continues in chapter three covering five key issues. The section on decolonising the curriculum makes a convincing argument for reviewing how existing curricula represent "minoritized" communities and their historical and current contribution to design and technology, asking the question of where do our students from all backgrounds see themselves in the materials we present them with. The chapter goes on to explore research around gender stereotyping and STEM subject uptake before the section on disruptive technologies calls for teachers to debate, dialogue and critique the subject in their classrooms, a theme revisited often in the book. The chapter on global warming sets out comprehensive evidence of climate change, its impact and potential solutions which could be used as a reference text for teachers looking to explore the subject in their classrooms. The final section covers a range of both challenges and possible solutions to issues around pollution and waste, much of which could be easily adapted for use in the classroom.

Chapter 4 Planning your design and technology curriculum

From this point on the book's intention is to challenge teachers of the subject to consider the nature of the subject they teach and their values to how to effectively plan, deliver and assess the subject in the light of these challenges and considerations. The chapter on planning the curriculum includes key information on materials, manufacture and functionality and how to design into a curriculum which allows space for critically engaging with the values and issues previously highlighted. It goes on to look at not just physical resources but how human resources and intellectual resources can influence the planning and delivery of an innovative curriculum. In this section, there are think pieces that look at teamwork and modelling of design solutions and also strategies for leaders developing teams. The chapter goes on to consider classroom activities again looking at the possible benefits of designing without making and inviting the reader to plan for learning around "considering the consequences of technology". There are further helpful sections on how to plan a scheme of work along with a closing section looking at curriculum intent, implementation and impact in light of Ofsted inspections which highlight the author's intention to write a book of real use to those in charge of the curriculum in schools.

Chapter 5 Teaching design and technology

Chapter five begins by looking at cognitive science and popular models of learning such as Sherrington (2019) and Rosenshine (2010) before moving to the question of how students learn in the context of the design and technology classroom. Beaumont and Steeg explore teaching design and making skills and opt to include a detailed review of teaching control systems and structures, both core components for teachers of all materials specialisms in current GCSE specification. Again they return to key themes of how to teach critique and designing without making, offering ideas for how to do this in the classroom. Matt McLain writes about the demonstration as a signature pedagogy and James Pitt supports the author's call to bring critique into our design classrooms in two interesting thought pieces.

Chapter 6 Assessing design and technology

Chapter six quickly establishes verbal in-the-moment feedback as a powerful form of formative assessment and goes on to explore classroom talk in the context of a range of activities. As well as this, models are provided for peer and self-assessment at the end of activities. Throughout the chapter there are imagined dialogues between the teacher and student around design choices and so on with a thought piece by Malcolm Welch supporting reflective discourse in the design and technology classroom. The current UK GCSE assessment framework is explored and the chapter includes a lively critique of current assessment practice by Richard Kimbell. Shortly after Louise Attwood, head of curriculum at the awarding organisation AQA, is given a platform to argue in favour of the current system of assessment, an intriguing choice of contributors by Beaumont and Steeg.

Chapter 7 Supporting design and technology

In the final chapter of the book a range of factors and communities that can support the development of design and technology as a subject are highlighted. These other individuals and agencies range from the benefits of enrichment activities and CPD to links with STEM and primary schools. There is also a section reflecting on how those involved in the subject could engage with a range of interested parties from school communities to local industry and MPs. Here there is an explicit move made to engage with the Design and Technology Association (DATA) Reimagining D&T (2023), written in response to the worrying decline in the subjects uptake in the UK highlighted in the EPI report spotlight on D&T (Tucket, 2022). At the end of each section links to the DATA report are highlighted and the authors close the book with a call to design and technology departments in schools to develop their own vision and mission statements and to consider where they wish to put themselves within debates about the future of the subject.

Reviewer's Conclusion

I would recommend this book to anyone involved in delivering teacher education, design and technology teaching those in initial teacher education as well as early career teachers in the United Kingdom, although I am sure that those with an interest in the subject around the world will find much of interest here. I would particularly recommend this book to heads of departments considering how they deliver the subject in their settings in the light of the EPI report (2022) and to student teachers looking to explore, both ethically and practically, how the subject could be taught and assessed in the future. Given the worrying rise in numbers of non-specialists teaching across all materials areas in the UK (DfE, 2023) I think this is also an important reference book for teachers coming to the subject with other degree backgrounds and experience. The ambitious scope of the subjects covered means that some sections feel as if there could have been more to say, something that HildaRuth acknowledges early in the book. I feels too that some of the real life exemplar projects used to illustrate key points in the second half of the book, whilst they reflect current practice in schools, could have been more aspirational in helping to inspire new approaches to teaching rooted in new technologies and looking out to industry.

At the heart of this excellent book is a call for critique both of our practice as design and technology educators and for a move to incorporate critique into our classrooms. In light of the new UK government's upcoming full curriculum review promising a focus on creativity and problem-solving (Dickens, 2024) and its manifesto pledge to promote oracy (2024) this book can make an important contribution to debates around where the subject goes next.

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