Design and Technology Education: An International Journal

27.3

Design and Technology: An International Journal

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Editorial: First DATEs

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Readers of the DATE journal who also engage with *LinkedIn* may have noticed that the Design and Technology Association, sponsors of *Design and Technology Education: An International Journal*, have just launched a new visual brand across all aspects of their media, including our journal. As editors, we have worked with them to create the new look, most notably the front cover. This re-branding exercise stimulated an interest to look back at previous 'brands' of the journal. This took us back to the Journal's provenance, starting in 1967. The starting point was a journal initially titled *Studies in Education and Craft*, renamed in 1970 as *Studies in Design Education Craft & Technology*, founded by the late John Eggleston who was also the editor of this journal and the one that it transformed into - *Design and Technology Teaching*. The first journal was ground breaking in its scope:

> *The journal is designed to focus attention on developments in the whole field of design and craft education ranging from art through the crafts to applied science and technology. It pays particular attention to case studies of new approaches in schools and colleges written by the teachers and tutors undertaking them. A selection of the growing number of important researchers and studies in design education is an important feature of the journal as is the review of all important new literature.*

The initial cover design was very much of its era – somewhat minimalist. But the cover of the much later edition in 1988 hints at the shift that occurred in 1990 when the journal was re-formulated as Design and Technology Teaching that focused on research, teaching and resources, as can be seen in Figure 1, with apologies for the image quality.

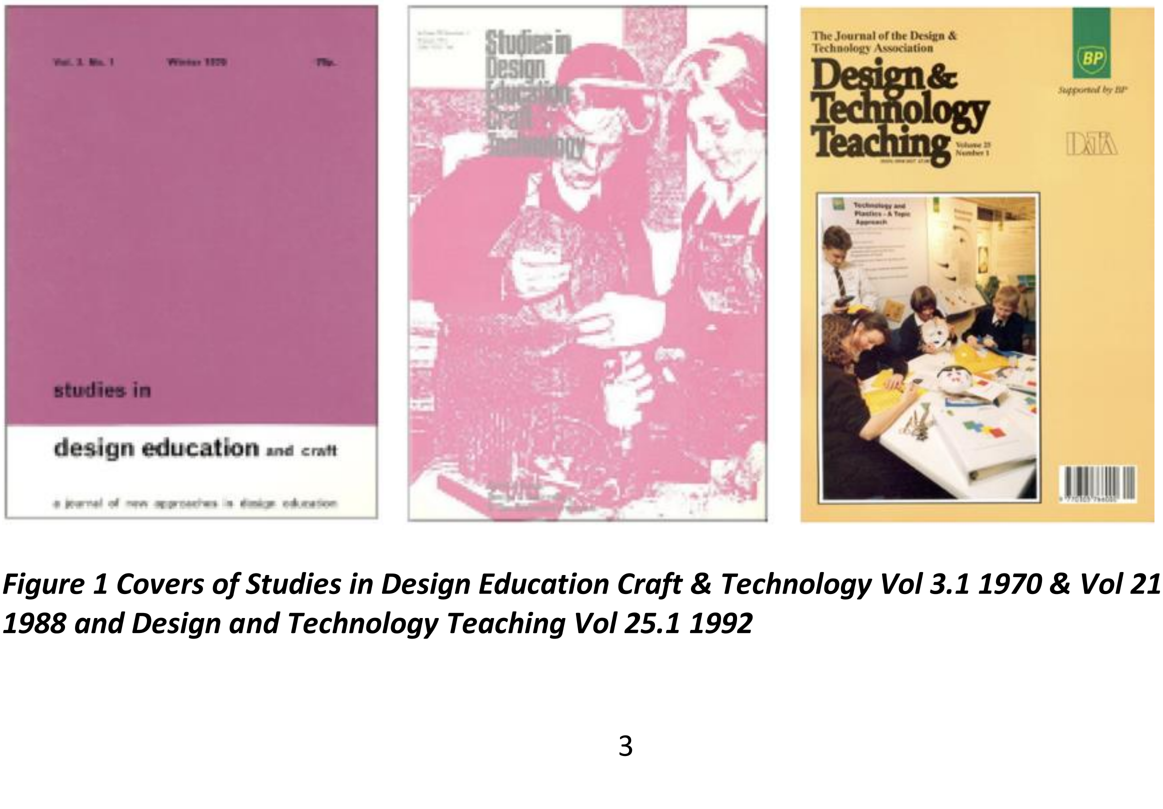

Figure 1 Covers of Studies in Design Education Craft & Technology Vol 3.1 1970 & Vol 21.1 1988 and Design and Technology Teaching Vol 25.1 1992

The newly formulated journal was launched at the same time as the new English and Welsh National Curriculum and included articles very much focused on this major shift, again illustrated by the cover image showing learners collaborating on a design project. Interestingly, in John Eggleston's initial editorial he also highlighted the launch of a new journal where the focus was explicitly on research – what is now the Springer *International Journal of Technology and Design Education*.

1995 saw yet another change in title, focus and brand for the journal, which was explicitly divided into three sections: Research, Curriculum Development and Reviews. John Eggleston indicated that through the increased focus on research that the journal was "returning to its roots as once again we turn to the search for sound knowledge and firm foundations rather than political rhetoric to guide our development of Design and Technology Education". With the shift came new branding that headlined the tripartite sections, shown in Figure 2, and also a new Editor as Richard Kimbell took over the reins. Also, to mark the shift to greater research focus the journal started in 1996 with a new ISSN and newly numbered as Volume 1. Ten years further on the journal was transformed again, marking its increased international research and making the major focus on research. The shift came with a new title, *Design and Technology Education: An International Journal*, a new Editor as Eddie Norman took up the baton, and new branding indicating the international nature. Now fully established as an international research journal, and in line with the rebranding of the journal's sponsor, we are launching a new visual identity – which could be seen as coming full circle as the journal's new cover is the closest to a minimalist approach that has been used since 1970, as shown in Figure 1. Serendipitously, even the pink will return for future Special Issues!

Figure 2 Journal of Design & Technology Education Vol 1.3 1996, Design and Technology Education: An International Journal, Vol 27.2 2022 and Design and Technology Education: An International Journal, Vol 27.3 2022

But throughout all of the iterations of the journal, the broad view of what John Eggleston highlighted in 1970 as the focus on research across "*the whole field of design education, ranging from art through crafts to applied science and technology*" remains as the continuous thread – as is illustrated by the articles in this latest issue.

In this issue of the journal we present four research articles, the first one of which focuses on higher education and the pedagogic and technical challenges of teaching and delivering online global collaborative courses, and the subsequent three articles from Norway, Sweden and Finland focus on secondary school education and the development and application of skills in design technology subjects.

In *Online Course Design Using Iterative Workshops on Computer-Supported Collaborative Design for Engineering Design Students*, Ross Brisco, Robert Ian Whitfield, and Hilary Grierson of University of Strathclyde, UK discuss the issues surrounding collaborative global design classes, specifically concerns around the skills that are required to ensure success in participation of online courses. The recent rapid growth of online courses in design and engineering such as *Global Design Projects* and *Global Design Studio* has exposed many students to this new form of learning for the first time. By observing students participating in global design classes at 2 UK universities they found that these classes were often selected by students without consideration of their suitability for this unique form of learning. The authors discuss the pedagogical and technical challenges of introducing these collaborative online activities across multiple locations. They went on to develop a short online course in computer-supported collaborative design over three years to bridge this skills gap with students self-diagnosing their skills requirements, with the authors then identifying which of these skills could be developed through educational interventions. This method could have wider applications for those developing courses in new or unfamiliar educational contexts and for those looking for students to perform a skills gap analysis to diagnose their own developmental needs. Although the research was conducted pre-Covid the results clearly identify the skills required to successfully participate in these challenging new forms of teaching, and help to inform those who are looking to implement an online collaborative element to their programmes of the technical and pedagogical challenges.

In *Developing spatial literacy through design of built environments: Art and crafts teachers' strategies* Ingri Strand and Eva Lutnæs of Oslo Metropolitan University, Norway, consider the challenges of the process of translating ideas for architecture and built environments into visual and physical representations, and how spatial literacy can be developed in pupils and students. Designing for the built environment has been a part of the new Norwegian national curriculum since 2020, with *Arts and Crafts* forming a key element of primary and lower secondary education in Norway. The authors explore the nature of spatial skills and how these can be developed through practical, hands-on activities in schools, going from abstract theories into concrete artefacts using 3D models. Embodied experience through full-size environments was utilised along with CAD visualisations, using points of reference, and connecting floor plans to standards and measurements. These methods helped pupils to use their own bodies and their own experiences of spatial relationships. Through a series of semi-structured interviews of secondary school teachers with varying degrees of experience, the authors identified key teaching strategies and through development of a visual model they hope to demonstrate to pupils their potential role in the process of designing built environments. They also provide examples of a wide range of tools and strategies for use when developing spatial awareness and spatial literacy in pupils. The authors hope that this research will contribute to the development of specialist vocabulary used in the teaching of 3D design and architecture and the built environment within schools, and perhaps help to create a greater appreciation of the importance of spatial literacy and sensitivity to space in the built environment to the wider Norwegian population.

In *Affordances of models and modelling: a study of four technology design projects in the Swedish secondary school*, Björn Citrohn of Linnaeus University, Karin Stolpe, and Jonte Bernhard of Linköping University, Sweden and Maria Svensson of University of Gothenburg, Sweden, investigate through interviews with Swedish technology teachers how students use models to solve design problems in technology education, and how the process of 3D modelling in STEM subjects using trial and error helps make problems visible and relatable, and how it helps them take inspiration from the solutions of others. Although there is previous research on the use of models in teaching design, there is very little on affordances of models and modelling in design projects, especially in schools education. Engineering design is described by the Swedish National Agency for Education as *the designing part*, and *the production part*, with only *the designing part* performed in schools as part of the engineering design process. The authors discuss the challenges of pupils allowing the availability of modelling materials to dictate their designs and influence their models rather than explore their ideas through the modelling process. Encouraging pupils to explore the affordances of their models – the relationships between the objects, users and connections – will help them to understand the properties of their models and to explore the possibilities of their function and use. Four projects are studied – a bridge, optical telegraph, chair, and greenhouse, and these are used to explore the emerging themes of materials used, drawings as models, and processes of conceptual design. They conclude that the use of physical models enables students to see different solutions, and to find and explore limitations in these solutions, and they also highlight the benefits of exposing them to a wide range of different materials to use in their modelling processes. The benefits of trial and error and reflection in action, rather than simply unreflective doing, are highlighted as key benefits of this work in helping to develop variety and creativity in a design process.

In *Development of Students' Technical Abilities between 1993-2022 in Finnish Comprehensive Schools*, Ossi Autio of University of Helsinki, Finland aims to trace the development of technical abilities in affective, psychomotor and cognitive areas in Finnish school children over the last 30 years. Around 300 pupils were tested in 1993, 2002 and 2022 using the same test equipment and protocols. Although some girls' test groups showed some positive changes in affective areas, all test groups showed a reduction in psychomotor and cognitive areas. This may be due to the reduction in the availability of craft and technology lessons or due to wider changes in society, with pupils showing a tendency to favour aesthetic over technical issues in their work. While Handicraft is now taught to all Finnish pupils throughout their compulsory schooling since 2014, there is now only a minor emphasis on technology, with art and design and aesthetics taking priority over technology and function. These changes have been reflected in the education of craft teachers, with time split between different areas of expertise and subsequent loss of depth in either area. Although there is some discussion on how we can define and measure technical ability in a simple and reliable manner, it is clear from the results that there had been a sharp drop off in the technical knowledge and reasoning of pupils, with some distinct differences between girls and boys. The author discusses the ongoing debate in Finland as to how this should be addressed, and whether technology education should be materials driven and design process based or more theoretical classroom based, with a lack of clarity among some parties of the relationship between craft and technology. The author concludes by saying that is clear that although there have been many changes to Finnish craft and technology education in the last 30 years, the ideal solution has yet to be found.

Finally, in addition to the research articles we present a book review by Willem de Bruijn, Arts University Bournemouth, UK of the recently published *Progressive Studio Pedagogy: Examples from Architecture and Allied Design Fields* edited by Charlie Smith with contributions by Sean Burns, Magda Fourie-Malherbe, Gerhard Griesel, Charlie Smith, Andrew R. Tripp, Anika van Aswegen, and published by Routledge.

Online Course Design Using Iterative Workshops on Computer-Supported Collaborative Design for Engineering Design Students

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Abstract
Based on observations of global design classes at different institutions, students selected technologies without justification for the suitability of the technology to support their collaborative design activities. To best support students in their collaborative endeavours, a short online course in computer-supported collaborative design was developed. The process of the creation of the short online course was unique using students' identification of their gaps in knowledge during workshops, iteratively over three years to develop a complete educational experience. Workshops were conducted with students to identify gaps in students' knowledge that were addressed at future workshops, by filling these gaps and conducting the same gap finding activity the researchers can identify if these gaps can be filled through an educational intervention. Surveys were used to evaluate the success of the development of an online course in Computer-Supported Collaborative Design (CSCD). The method for the development of the short online course was logical and successful based on feedback from students during surveys. The outcomes of this method can have implications for those developing novel courses in familiar teaching environments or new digital media. This research has identified the interventions required to prepare students for global design projects in a novel way. Lessons from this research will support other educators to consider their course development practice

Keywords
Course design, Higher education, Multidisciplinary, Virtual teams, Collaborative design, Student learning experiences.

Introduction
Collaboration is commonplace in engineering design education with the trend towards projects and problem-based learning. Learning-by-doing, Active learning, Experimental Learning and other empirical based constructionist theory learning mechanisms have been critically influential for how engineering is taught in the 21st century (Williams, 2017).

In recent history there was a trend in engineering education to introduce abstract conceptualisations taught within lectures to transmit knowledge from professor to learner. However, this has commonly been replaced with interactive learning interventions that enables experiential learning (Sole et al., 2021). Lab and tutorial work was frequently used to strengthen understanding of the learner and confirm that the learners understand the concepts that the professor is teaching (Christie & de Graaff, 2016).

These educational theories document a trend towards models of learning where active participation justifies experience, reflection and abstracting such as is theorised in the Kolb cycle of experiential learning (Kolb, 1984). Through active engagement students are building real-world skills that future engineers require. This is not simply the facts and physics that govern our reality, however, this is the analytical and critical thinking skills essential for complex challenges in modern engineering. The skills built are how to think about these challenges, students require training to develop these skills (Dewey, 1910).

From early theories of philosophy, Aristotle lead the way for theories of Empiricism, "anything learned is gained through interactions and associations with the environment" (Schunk, 2011). Knowledge is developed from interactions with the world, and these interactions can build to form complex ideas. Fundamentally, this is to reflect that the learner is involved with the learning process. The learner creates meaning from the experience (Bednar et al., 1992)

For engineering design in particular, this is reflected in the development and learning of skills that engineers acquire. There has been a noticeable change in the way engineers are educated and a focus on softer skills within engineering (Sole et al., 2021).

Modern Engineering Design Education

Changes in education are impacted by the tools and technologies available. As evidenced by the accelerated change to online learning as a result of COVID-19 (Fleischmann, 2020). An acceleration in the transition to the use of technology to support engineering design education and engineering design in practice. However, this change was prefaced with motivations towards online learning throughout the 2010's. The emergence of Massive Open Online Courses (MOOCs) (Sezgin & Sevim Cirak, 2021), remote learning courses (Balamuralithara & Woods, 2009), multi-campus learning (Sielmann et al., 2021) and improved Learning Management Systems (LMS) with increased functionality for multimedia (Hussain & Jaeger, 2018) have all contributed towards online learning as an equal experience to traditional in-situ learning on campus. In certain cases, there are examples of how online learning has gone beyond the learning experience that can be facilitated in a traditional environment (Smart & Cappel, 2006; Luo, 2019; Qiu, 2019; Yu et al., 2018).

With increased opportunities for learning comes increased opportunities for complexity in the learning experience. This has been observed in the Global Design Projects (GDP) class since its inception in 2007 with more robust studies on the impact of technology in supporting students learning experience since 2015. Since 2010, it was observed that students would choose to use social network sites and mobile devices to communicate with distributed student team members from other partner Universities located in London, Malta, Budapest, Finland, China, Australia, New Zealand, and the USA (Brisco et al., 2016). This practice was successful in facilitating communication between team members and supported collaboration when conducting digital design activities. This provided a motivation for educators of the class to better understand the technologies students choose and justification for these choices.

In previous years of the class, 2007-2011, technologies such as video conference, email, wiki pages and forums were used to facilitate communication (Mamo et al., 2015). This observed change towards using social network sites and other social software such as (instant) messengers from 2011-2019, enabled devices like smartphones to be used by students as a primary computing and communication device. This also led to a change in student behaviours from formalised video conference meetings to quick and short communications between students wherever and whenever there was time to reply to a query.

The observations made around the GDP were not unique to this class. Student's behavioural changes in the use of technology had been documented in the literature from 2012 (Hurn, 2012; Gopsill et al., 2015; Mamo et al., 2015; Pektaş, 2015; Klimova, 2016; Brisco et al., 2018).

Why do engineering design students need education on collaboration technology?

There is criticism of learning technology research as highlighted by Beetham and Sharpe (2019), who stated: "Teachers who are excited about these technologies are often accused of using them regardless of whether or not they are pedagogically effective, and even in ignorance of the long tradition of pedagogical evidence thought." If state-of-the-art practices can be identified and implemented within a classroom activity, students will have the experience of building skills in these areas, that are relevant to current practices.

Although there is much published in the literature concerning the benefits and problems of using novel technology, it does not make its way back into the classroom due to a lack of awareness or time constraints of the educators (Brisco et al., 2018).

In addition to participation, students can meaningfully reflect on their interactions with other team members. Reflection is a large part of a good educational experience (Thornton, 2013). And a particular skill to be developed by students in reflective thinking and reflective writing (Grierson, 2010). Within a team, students can discuss and revisit topics that help to develop the design. This is within education and industry based on the link between reflection and design performance (Tang et al., 2012).

Developing students' digital literacy contributes towards readiness when students enter industry, as greater emphasis is placed on teamwork, technology, and globalisation (Andert & Alexakis, 2015) particularly post-pandemic (Stange, 2020). Educators have a responsibility to ensure, where available, that state-of-the-art practices are being imparted to students.

If inadequate technologies are selected, the student team may decide to fill in the gaps by employing more technologies that add additional complexities such as a greater number of communication channels or complex team protocols for managing the sharing of information (Sclater, 2008).

Pedagogical consideration

To develop skills in digital literacy, students must experience digital technologies within a protected environment, as identified by Bohemia & Ghassan, (2012), who stated: "We propose that the proliferation of Web 2.0 technologies and their incorporation into the learning and teaching environment means that academic staff and students will need to develop skills in digital literacy to participate effectively in distributed project-based collaborative work". These skills can be developed in an educational context to benefit future workers as identified by Gopsill, (2014), "If the benefits of technology skill-building could be better understood and communicated to students the next generation of workers will be in a better position to adapt to a modern, agile and dynamic workplace."

Emami, (2009) highlighted a trend in engineering education towards the constructionist learning model. The constructionist model assumes knowledge is created in the mind of the learner based on outside stimuli. For example, within a team discussion, one idea might stimulate the idea of another person based on the interpretation of the idea. The constructionist model is representative of Project-based learning and is supported by reflection activities after learning has taken place (Yang, 2010). The behavioural model supports a traditional lecture style suggesting that knowledge is passed on, for example, from a person to a person, a book to a person, a video to a person etc. (Emami, 2009). Both models reflect well-held world views.

In recent years, pedagogical assumptions in engineering education have focused on the student experience with a focus on how students learn in comparison to what they learn. The strategies active learning promote are useful during team activities to encourage self-learning within a team environment. Engineering work tends to be multidisciplinary and then requires the skills to engage in these types of projects that an educational environment can prepare (Ledwith, 2017). When students are within a team environment they rely on self-learning in research of the topic, and this means students take a share of the responsibility to learn (Kinzie & Kuh, 2004) and can increase knowledge, motivation, and commitment (Núñez-Andrés et al., 2022).

Considering the lessons of global design and the need to instruct students about the requirements of technology use in design and the importance of technology selection, a combination of the theories of learning is required (Ertmer & Newby, 1993). Constructive learning unlocks the fundamentals of theory that students can later experience and reflect upon. And as proposed by Bohemia & Ghassan, (2012) a combination of theories enables the development of skills and digital literacy, that cannot be assumed for all students.

Building an educational experience to Supporting Technology Selection

To support successful technology selection, students and educators must understand technology functionality available and how this functionality satisfies the requirements of the collaborative project work.

The change in the technology used to communicate and conduct collaborative activities, and the change towards novel technologies appeared to support teamwork. Certain teams reported fewer inter-team issues when using technologies (Brisco et al., 2016) and by delivering guidance on technology selection based on what was known at the time within the literature, and experiences from previous iterations of the class, team collaboration issues were reduced (Brisco et al., 2017).

In the following sections, the outcomes of five workshops are reported. The purpose of the workshops was to identify the gaps in knowledge of engineering design students working in collaborative teams. The intended outcomes of the identification of the gaps were to understand how to support students in future years to fill these gaps in knowledge. To fill these gaps, literature was used on the requirements of collaboration in engineering design teams.

Research Methodology

The motivation of this research was to support the identification of suitable technology for collaborative engineering design teams and to develop an educational experience with the purpose of filling the gaps in knowledge of the challenges in technology use by collaborative engineering design teams, and of technology selection practice.

To achieve this motivation the research must identify:

RQ1. What are the challenges in design practice for teams that technology influences?

This research question is initially answered by a systematic literature review to identify the factors that influence successful Computer-Supported Collaborative Design (CSCD) (Brisco et al., 2020). These factors were systematically mapped and categorised to create 19 CSCD requirement statements that formed the basis of the initial workshop lesson. Students will contribute to answering this question by contributing their own knowledge of the challenges they face in collaborative engineering design teams.

RQ2. What are the gaps in knowledge students have, that can be filled by the literature?

This question is answered by conducting workshops with students to identify the challenges faced in collaborative engineering design teams and how to overcome these challenges. If new challenges and solutions are identified, they will make their way into future workshop lessons.

RQ3. Can these gaps in knowledge be filled with a designed educational intervention?

Students taking part in workshops will have the benefit of the knowledge of the literature and of the solutions to gaps in knowledge identified at previous workshops. To answer this question, a design experience was created based on the format and success of the workshops. To ensure students could engage with the class wherever they happen to be in the world, whichever time zone and with restrictions of COVID-19 meaning students would work from home and in their own time, an online course in CSCD was designed to educate on the challenges faced by engineering design teams and how to overcome these challenges, and how to systematically choose technologies based on an understanding of the requirements of collaborative engineering design.

Developing the workshop in CSCD

A systematic literature review was conducted to identify the factors that influence successful CSCD for the design of the workshop in CSCD. The purpose of identifying the factors in the literature was to build knowledge on what was already known about the challenges of technology use in engineering design teams, to educate students on the challenges and how to overcome them. A lecture was created that details the challenges faced.

To support understanding and reflection on the factors that influence successful CSCD, an activity was implemented into the workshop. Students feedback on the outcomes of each part of the workshop to the larger group justifying their decisions. The activity was designed in three parts to support students' educational development.

1. Students are asked in teams to discuss the challenges they face in collaborative engineering design teams.

2. Students are asked to choose three challenges (due to time restrictions) and discuss the functionalities of technology that would help them to overcome the challenges.
3. Students are asked to make recommendations to future engineering design teams on how they can overcome the challenges using technology.

The design of the workshop follows blooms revised taxonomy (Anderson et al., 2001), where students remember experiences from past group projects, understand the experiences through discussion, apply in the context of conceptualising technology functionality (new context), analyse in the context of identifying suitable technology, evaluate by justifying their decisions to the larger group and create new recommendations that can be applied within their own groups or future groups.

Over the years (2016-2018) in which the workshops were conducted, the workshop activities did not change, however, the content of the introduction and conclusion presentations were updated iteratively based on the outcomes of the previous workshops, new literature being published on the topic or questions students had following the workshops. To conclude the workshops section of the research, students who took part in workshop five were asked to identify best practices in conducting collaborative projects.

Table 1 – summary of the workshops over time

Workshop	Class	University	Year	Participants
1	Global Design Project	Strathclyde	2016	26
2	Global Studio	Loughborough	2016	26
3	Global Design Project	Strathclyde	2017	18
4	Global Studio	Loughborough	2017	28
5	Global Design Project	Strathclyde	2018	27

The University ethics procedure was followed with consideration that students as part of the workshops were not advantaged by the learning of the workshop against others within the same class year. The opportunity to take part in the workshops was available to all students.

The first, third and fifth workshop involved students of the Global Design Project class at the department of Design, Manufacturing and Engineering Management, University of Strathclyde with 26, 18 and 27 students respectively, and the second and forth workshops include students of the Global Studio class at Loughborough University School of Design and Creative Arts with 26 and 28 students respectively. 125 students participated in the workshops over the years. A summary is included in Table 1.

Teams of students were formed of between four and eight participants. Students were invited to form their own teams usually with the teams they had been assigned within their projects class. Students of the Global Design Project were Master level final year students from multidisciplinary and multicultural backgrounds. Students of the Global Studio were Bachelor's level final year students. Both projects were based in product design, the degrees attract a high percentage of female students where the class average is around 50% male to female students. The average age of students was 21 years and two months across all workshops.

Teams were supplied with paper, marker pens, and sticky-notes to complete the workshop activities. Teams could record and display the knowledge in whichever way they felt was most appropriate, e.g., lists, mind maps, and sticky-note ideation. Individual outcomes of the workshops are collated for download at: doi.org/10.15129/9647d268-c35a-4c6e-a325-caabbf64c42e

Results and development over time of the workshop

Within this chapter the gaps in knowledge identified by students are defined with the aim to display the development of the workshops towards the creation of an online course in CSCD. Figure 1 displays the development of the workshops with the gaps in knowledge identified. The gaps and development are discussed in the discussion chapter.

To support students understanding of gaps in knowledge identified in workshops 1, additional information was added to confirm that different students will have different expectations of the projects and will also have different contributions due to the requirements of the outcomes of the project at different institutions i.e., the project is a core module at the Scottish University and elective at the Malta University. Helping students to understand that the desired purpose of the product is different for all stakeholders, and that this reflects projects in real-world scenarios was welcome.

This is related to levels of competence of the students who come from different disciplines with different skills and capabilities. Including information on the importance of confirming language and methods outcomes such as using ID Cards (Evans & Pei, 2010) supported the alleviation of problems with substandard outcomes or misunderstandings. This also helped to overcome a common understanding of the problem by encouraging confirmation by all team members on their individual understanding of the problem and the design method they would use to investigate or overcome the problem.

Signposting students towards functionality of digital tools for democratic decision making such as polling tools supporting the gap of the importance of encouraging debate and democratic decision making. This is related to the gap of choosing appropriate technology and lead to an investigation of which technologies are best to support students in CSCD (Brisco et al., 2020). However, it was important to include as part of the workshops information about relevant technologies that may be able to support and why these technologies are appropriate. Students were then encouraged to evaluate technologies throughout their own design projects.

Technology introduced barriers to students where there are solutions at industrial levels that have been researched including Product Lifecycle Management (PLM), data management and recall systems from the likes of Oracle, Autodesk, Siemens, and PTC. Students are unaware of these as they are too expensive to implement or take too long to learn and set up within an educational environment. Alternatives to support data management were emerging at the time of workshop one including Slack and Microsoft Teams. Awareness of these by teams would support understanding of capabilities for future projects.

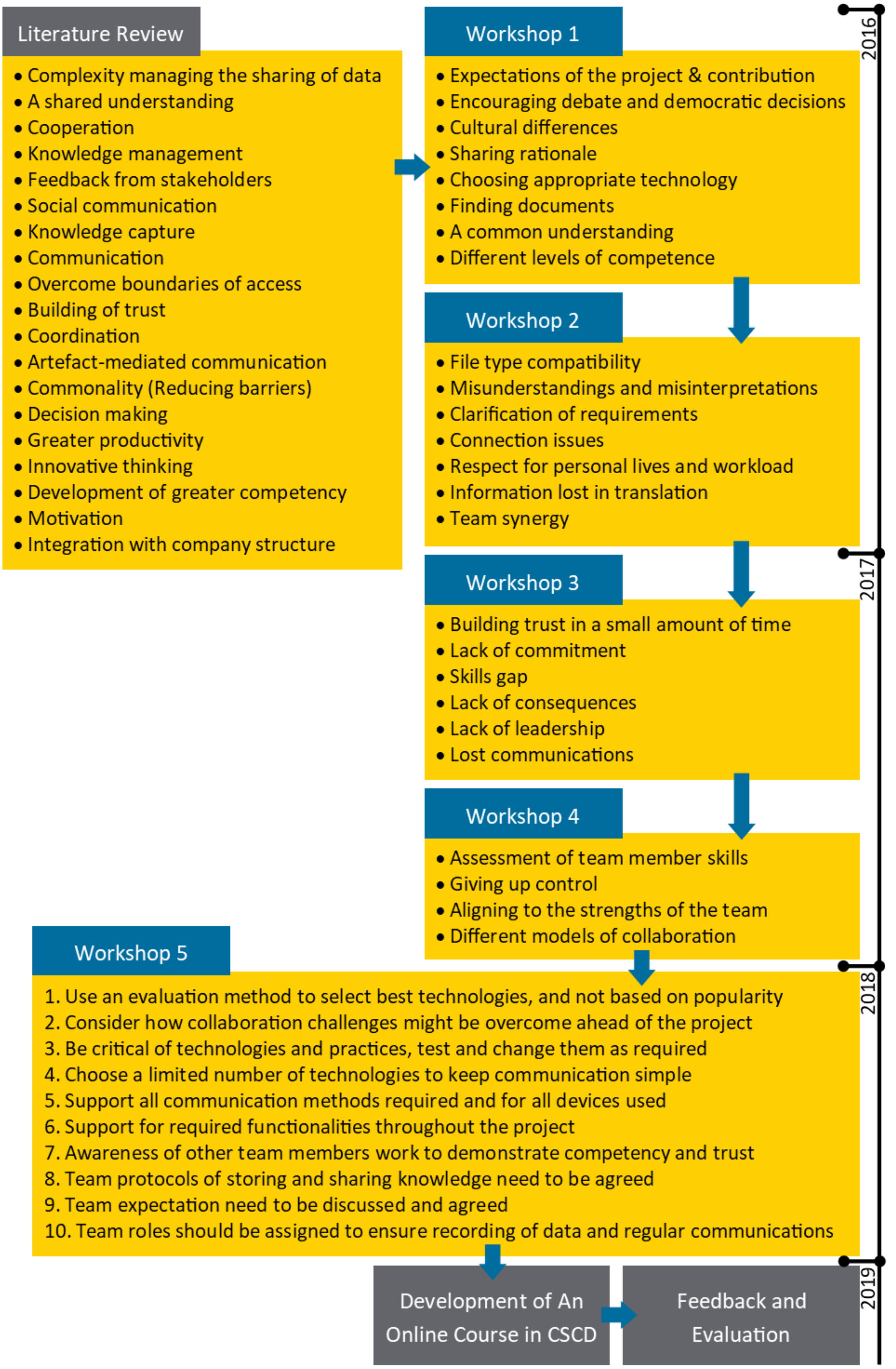

Figure 1 - Graphical representation of the workshop development and gaps in knowledge identification.

Cultural differences were difficult to address due to the nature of the class. Students do not have the time to develop an understanding that cultural differences exist, however they do understand that they have an issue with a particular sub team located in a particular country or with individuals. One example of this is students in the UK believing that the students in Malta are always at the beach, enjoying the sunshine and not focusing on work. This misconception comes from differences in students' cultural misunderstandings about the dedication of students towards their work and is related to the fact that students in Malta are not graded on the outcomes of the class and tend to be of lower year groups where they have more free time in their curriculum. To overcome this gap, students were encouraged to create agreements about working times e.g., 9-5 typical working times, and to create regular meetings to function as motivation for all students.

Due to language barriers, there are issues of sharing rationale. A video was added to the second workshop featuring Starbucks at a Facebook keynote event where the CEO of Starbucks shared his rationale for the use of Facebook for business between shop owners. The sharing of the rationale is crucial to understanding the reasons behind decisions made.

The gaps in knowledge identified by students in workshop two are as follows.

Students in workshop two had novel concerns related to working in groups with students in different time zones, who have different native languages and with major cultural differences. Often information was misunderstood and misinterpreted, requirements were not clarified, and crucial information was lost in translation. Towards Workshop three a technique was added to the lecture to encourage students to double check understanding of instructions i.e., when a student asks another to conduct a task, the other student must repeat back their understanding of what is required. This simple method has the potential to overcome common issues of translation and the same can be completed in text-based communication using a comments system.

As students were more likely to be working with others in faraway countries. Common software and then file types were difficult to manage. A frequent problem experienced in real-world design projects. Students were encouraged to discuss software and evaluate it at the beginning of the project rather than assuming that these barriers could be overcome later.

Due to distance and students relying on home or sometimes mobile internet connections, students did experience connection issues during video and audio calls. Students were encouraged to evaluate software ahead of the projects to determine which software is best for all team members and to try alternative methods i.e., if video is difficult then a phone call may be best, text-based communication could play a larger part in the collaboration, or recorded video/audio messages back and forth.

Once again students were encouraged to define procedures for working such as a standard 9-5 working time during the day and to understand what an acceptable time to respond may be for different communications.

Finally, team synergy was difficult to encourage however encouraging social communication was one way to overcome this that was included as advice in workshop 3. Students may decide to have a social gathering such as eating a meal virtually together. This also supports cultural understanding.

The gaps in knowledge identified by students in workshop three are as follows.

Again, aspects of commitment were raised as a gap in knowledge to overcome. However, another gap did provide a potential solution being lack of consequences. Without consequences for not completing work, other team members would pull up the slack. Again, the answer became encouraging students to make formal agreements at the start of the project of processes and procedures. Beyond this, there was a need to allow students to understand that differences in commitment are common in real-world projects and experience is important in overcoming barriers.

Similarly, the short timeframe of the projects has revealed issues for team members in previous workshops, however during workshop three participants identified that building trust was a key gap in knowledge. To overcome this gap in workshop four, students were encouraged to conduct icebreaker activities and to share more social information. Unfortunately, there is a limit to overcome that may not be possible in such short timeframes of projects. Global design projects such as the EGPR have students collocated for a week to build trust (Kovacevic et al., 2018).

A skills gap was identified for individual students in different disciplines i.e., students involved in design activities who have limited design process knowledge. This became a lesson to educate the students that they will face barriers when those involved in projects come from multidisciplinary backgrounds and rather than dismiss this person's contribution, to find what is unique that they can offer. A mantra of future workshops became 'the right team member for the right task at the right time.' Again, this needs to be discussed openly at the start of the project.

The skills gap is also related to the identified gap of lack of leadership. This was described as a problem with decision making. A top-down company structure would result in the manager having the final decision on the direction, where students in the GDP were encouraged to be democratic. Therefore, decisions made that contradict a student's desire were frustrating to implement. This is a personal developmental lesson for students, and information was added to the workshops on the necessity to give up control during group projects and knowing when to progress for the benefit of the group.

Finally, lost communication was an issue raised at previous workshops in a slightly unique way. The issue of lost communication was having too many communication channels e.g., a message is sent on one platform (Facebook) and responded on another (WhatsApp) that causes confusion and difficulty in the recall of knowledge, rationale, or documents. To overcome this, additional information on technology selection was added to highlight the importance of choosing fully featured technologies and not those that had limited functionality which would then need to be supplemented with the selection of additional technology.

The gaps in knowledge identified by students in workshop four are as follows.

Assessment of team members' skills was difficult to advise on without causing offence to the team member being assessed. However, it is possible to give others a sense of skill through initial activities such as icebreakers. Asking students to collaborate on the design of a sketch, all contributing towards the design with their own drawing and suggesting ideas for improvement acts as both a way of team members introducing themselves and their practice to each other, however also a way of allowing each other to assess sketching abilities. The other area of product development where this could be useful is in assessing CAD skills. CAD skills are a mixture of design work and experience. Products can look very technical (blocky) and not very aesthetically appealing, that other students may think means that the student lack design skills. However, this is a communication error with determining what type of CAD model is desired and selecting the right team member to create this. Often software can also play an influence on the quality of CAD model that is created aesthetically. To support this aspect, further ideas for icebreakers were generated including a CAD brainstorm with initial models generated that must be assembled. This has one difficulty of finding a common CAD package, that has the advantage of allowing students to discuss CAD software packages early in the project and avoiding CAD compatibility issues later in the process.

Another aspect of skills and ability is aligning the project with the skills of the team. The students are asked to develop a product for the class; however, a design methodology or specific tools are not essential for the class. Students can develop the product in whichever way is best. To encourage discussion on the best way to collaborate on the design of the product examples of design projects using technology were added to future workshops including Wikihouse; that uses a wiki tool to collaborate on the design of an open-source house.

This relates to models of collaboration and how teams are structured. To introduce theory from collaboration research into the team's decision making, information on models of collaboration were added to future workshops including the 3C and Minnesota Computer Science Collaboration model.

Finally, a lesson was designed for future workshops at a higher level than those before. Giving up control is an important part of working in a team, both in terms of the direction the project is moving and individual decision making. As students are encouraged to be democratic in their decision making there needs to be an understanding that any one student cannot control every aspect of the product development including the quality of the outcomes. Some of the outcomes will not be exactly as expected, and this is normal for real-world design projects. It is also a lesson to learn that team harmony is more important in certain cases than the quality of outcomes of a small part of the project. This was discussed with students at future workshops.

Following workshop five, the intention was to cease the in-situ workshops and transition to an online learning experience. Towards this need, students were asked to identify best practices in collaborative engineering design working to be used as a guide for students taking part in short form projects.

These best practices became instrumental in the formation of an online course in CSCD to ensure students had a complete understanding of the challenges during collaborative student projects. The iterative design of the workshops ensured that gaps in students' knowledge were considered in the design of the online short course in CSCD.

Development of an online course in CSCD

An online short course in CSCD was envisioned, designed to include the knowledge developed over the course of the five workshops based on students' gaps in knowledge.

At the University of Strathclyde, the learning management system (LMS) is named Myplace and is a highly customised version of Moodle. A first draft of the class was created using Myplace, and although it would be possible to add external students from other universities to the platform, this would be a high administrative task for the staff of the class to manage. There was a need to find a common educational platform or LMS where students could engage in the content. An external LMS enabled full control by the course administrator and the ability to quickly scale to include other global design courses or augmented courses for other contexts.

LMS such as Edmodo, Google Classroom, Moodle, and Blackboard were assessed to find out if they had the required features and functionality. Moodle and Blackboard require personal hosting and a major investment in set-up. Edmodo and Google Classroom was not able to offer the ability to self-enrol in a class and to create lessons in which the user could engage in their own time. After further searching, NEO LMS (neolms.com) was found and offered a simple set-up and self-enrolling features required. A class could be created for the Global Design Projects class and a link could be shared to self-enrol reducing excessive administration.

NEO LMS was selected as the designed LMS for practical reasons. The features of NEO LMS that made it suitable for the class were:

- The ability to have a self-contained class with multiple lessons.
- Self-passed lessons in which students could engage in their own time.
- Functionality to support wiki style forums for class discussions.
- Multimedia functions for video integration.
- Surveys and quizzes to poll student opinions and test recall.

To ensure a comprehensive learning experience, Salmon (2013) five-stage model was employed to ensure that the online course was to appropriate standards. These are:

1. Students were welcomed and encouraged through introductory videos.
2. Small online introductory tasks helped to familiarise students with technology.
3. A demonstration of the course content explained how to engage and find information.
4. Lectures included in the course had knowledge-building activities.
5. Discussion and response were facilitated.

The short online course would consist of three lessons delivered over one week. This was to encourage reflection between lessons and the time for students to engage in additional activities such as discussion forums, used to build trust between students.

Students were recommended to engage in the first lesson on a Monday, the second lesson on a Wednesday and the third and final lesson on a Friday. Each lesson takes approximately 20 minutes to complete making the course 1 hour in total. Students work in their own time and can spend more time completing activities and reflecting if they wish.

Three lessons were developed and were formatted as follows:

1. An Introduction to CSCD

In the first lesson, students are encouraged to discover different technologies that may support their engagement in global collaboration.

- Introduction to the features and functionality of NEO LMS through self-exploration (Introduce yourself activity).
- Introduction to CSCD, typical CSCD technologies, their use and importance for education and industry applications.
- Posing questions about the use of CSCD in global design.
- Question "What are the challenges you may face during the project?"
- Link to ID cards for good communication (Evans et al. 2013).

2. Collaboration Models

In the second lesson, students are introduced to models of collaboration and are asked to reflect on successful collaboration endeavours.

- Models of Collaboration.
- What is Collaboration vs Co-operation, Communication, and Coordination?
- Examples of CSCD projects.
- Question "Which collaboration model might you use during a Global Design Projects and why?"

3. The CSCD matrix

In the final lesson, students are introduced to a matrix that supports technology selection for global collaboration projects.

- Introduction to the requirements of CSCD.
- Introduction to the functionalities of technologies that support CSCD.
- Introduction to the CSCD matrix tool for technology selection.
- Best practices for global design.
- Feedback on the course.

Screenshots from the course are included in Figure 2 – 5.

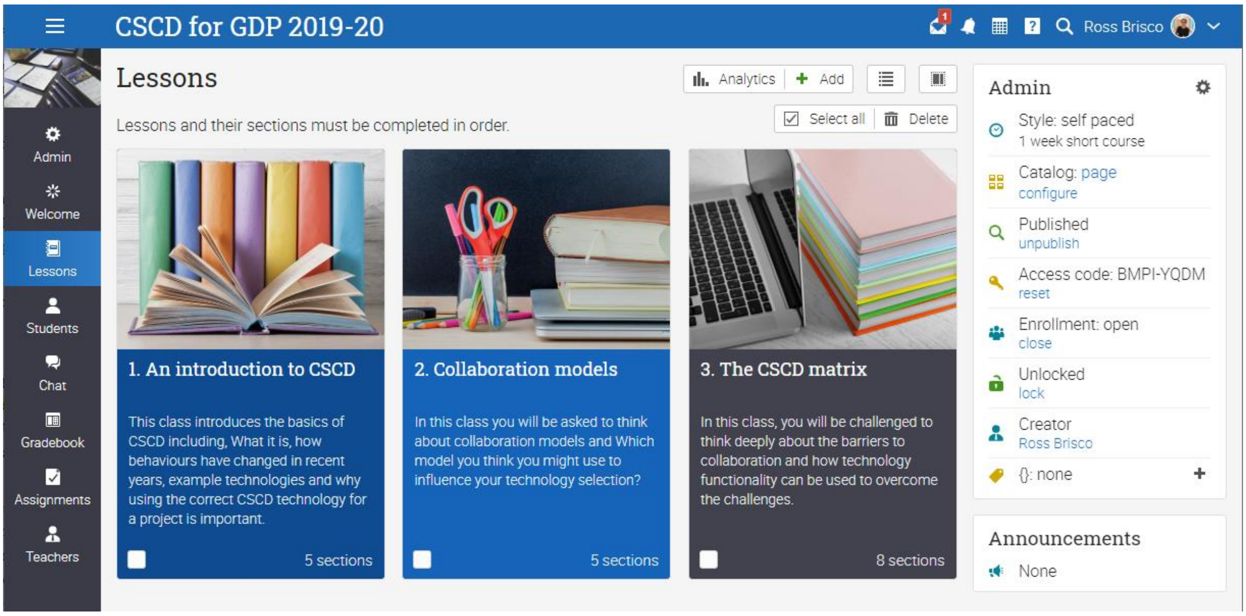

Figure 2 - The welcome page on NEO LMS and connections to the three lessons

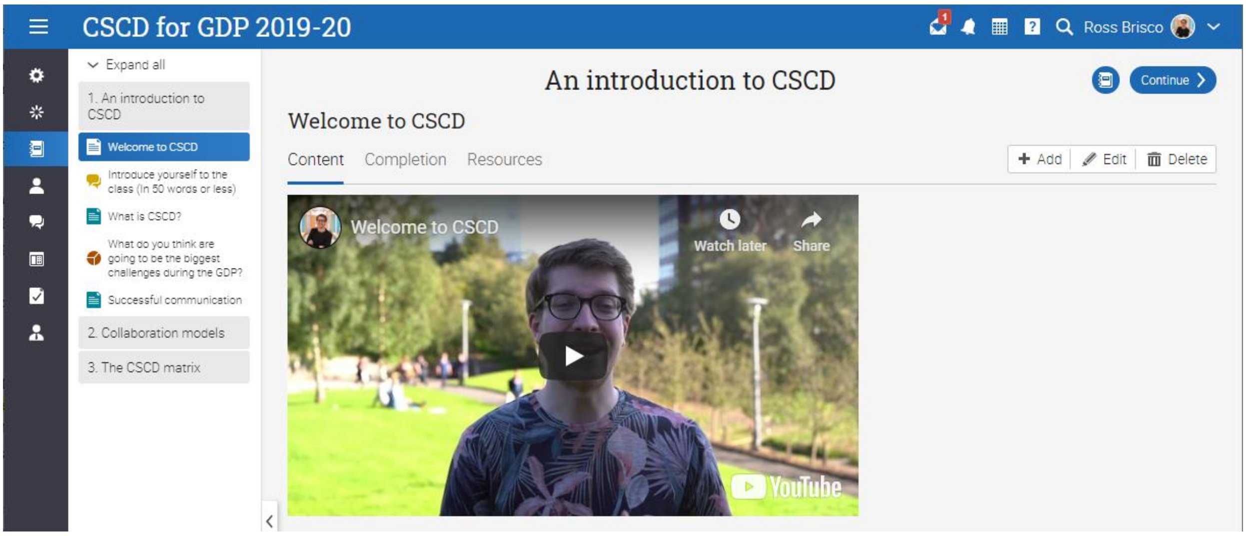

Figure 3 - The first video introduction for the first lesson

To support reflection, students are encouraged to revisit the previous lessons to recap and read comments from other students included in discussion forums. They are also asked to comment on any discussion posts that they find interesting. A mixture of video and text was used based on the content of the lesson. A test was used when simple diagrams might need study and focus, whereas video was used to build a sense of presence and connection with the students.

Text lessons were useful to convey additional information such as websites, connections to publications, connections to external videos or animations of processes. To assess knowledge and encourage reflection, students were challenged to think of answers to questions such as “Which functionalities of technologies were important to overcome challenges in global collaboration?" Students created their comments and then engaged in other answers by reading and responding.

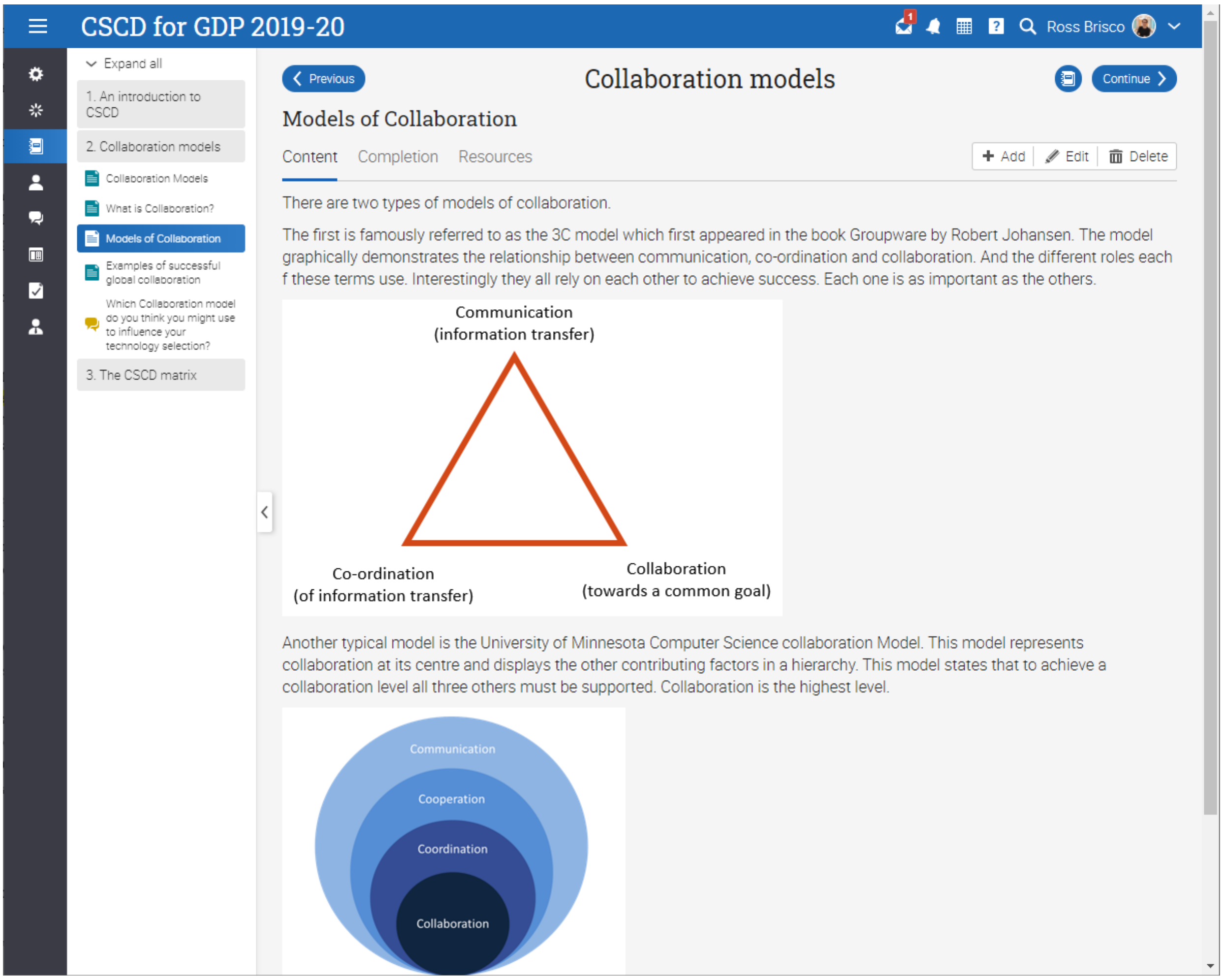

Figure 4 – Lesson on Collaboration models

Figure 5 - An example of a discussion forum to support reflection

Feedback on the online course in CSCD

Students of the first online course in CSCD were asked to provide feedback on their experience with the online course. Three questions were asked, and 38 participants responded.

The first question asked, 'How prepared do you feel for the Global Design Project following the online short course in CSCD?' The results (Figure 6) were positive with most students agreeing that they were highly prepared (14 of the 38 students) or somewhat prepared (20 of the 38 students). Three of the students felt somewhat unprepared.

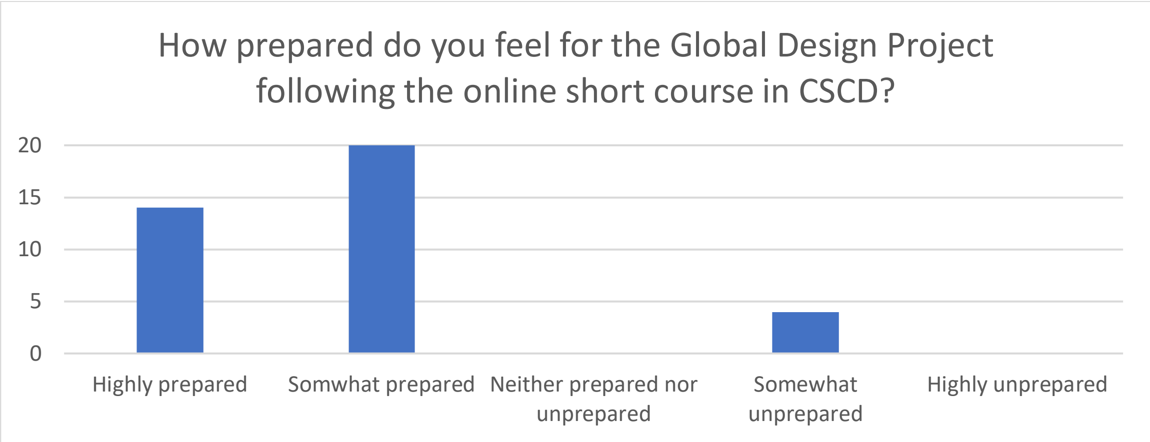

Figure 6 - Response to the survey question on how prepared students feel for their collaborative projects following the course.

The second question asked, 'How prepared are you to select technology based on the knowledge gained from the online short course in CSCD?' The results (Figure 7) were again positive with most students agreeing that they were highly prepared (19 of the 38 students) or somewhat prepared (16 of the 38 students). Three of the students felt somewhat unprepared.

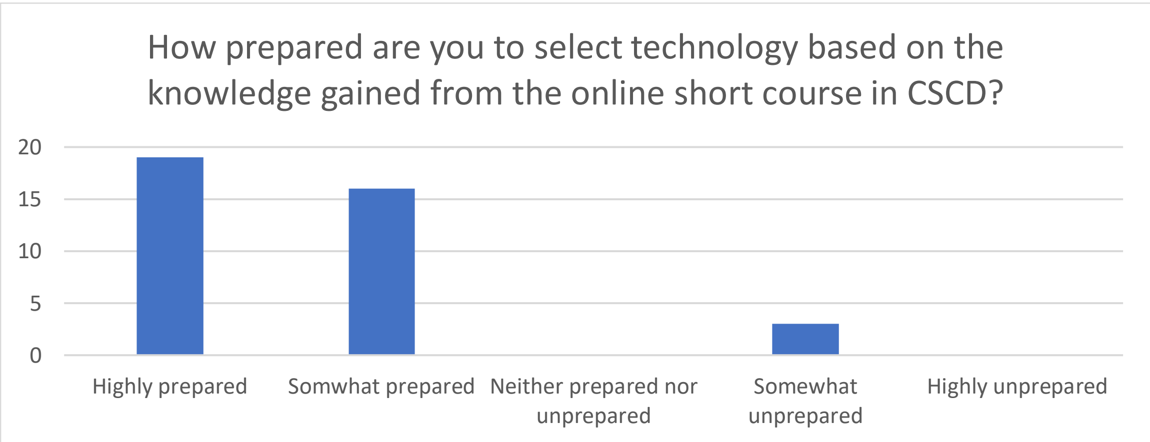

Figure 7 - Response to the survey question on how prepared students feel in selecting technology following the course.

An open response question was included in the questionnaire for any other feedback (Figure 8). This feedback was coded to understand future developmental needs of the class. Two students agreed that "More examples and case studies" would be useful and that "Terminology was difficult to understand" which highlights a trend if negligible based on the numbers. Other students commented they were "Confused by one or more parts of the course," "Difficult to contextualise knowledge," "Difficult to justify my own opinions," "Knowledge was contradictory with student experience" and "Overly complex for the lessons."

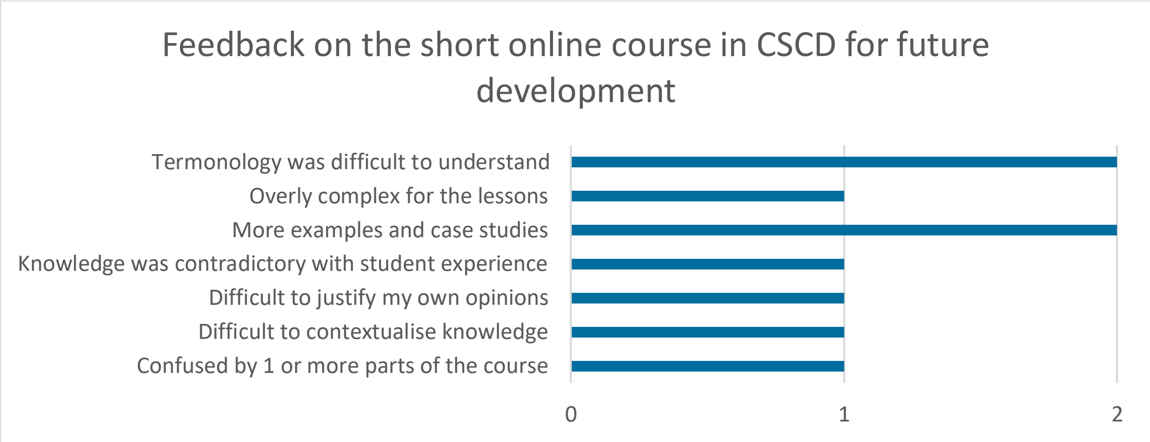

Figure 8 – Feedback received on the short course

Addition of the CSCD matrix to support technology selection

A major gap in knowledge identified during the development of the workshops was students having justification for the identification of technologies suitable for their projects. Students chose software they were familiar with rather than justifying their technology choice based on the merits of the technology and availability to all team members. If students had guidance on the requirements of technology for their projects, and a systematic way to choose the technology based on the requirements, then the learning associated with technology choice would be beneficial for their educational development rather than happenstance.

A solution was identified in the CSCD matrix (Brisco et al., 2020). That enables a systematic evaluation of individual technology or technology packages to determine if they have the functionality to support collaborative requirements. Students are guided to identify technologies, identify the functionalities of the technologies, and then link the functionalities with the requirements of CSCD that are already determined and categorised (from a literature review and thematic coding).

The CSCD matrix was first included in the 2018 workshop, with the majority of students in a follow-up questionnaire (Figure 9) agreeing that the matrix was highly relevant (18 out of 28 students) and the reminder that the matrix is somewhat relevant (10 out of 28 students). The other options were neither relevant or irrelevant, somewhat irrelevant, or highly irrelevant. All student's responded that the workshop contributed positively towards their understanding of CSCD.

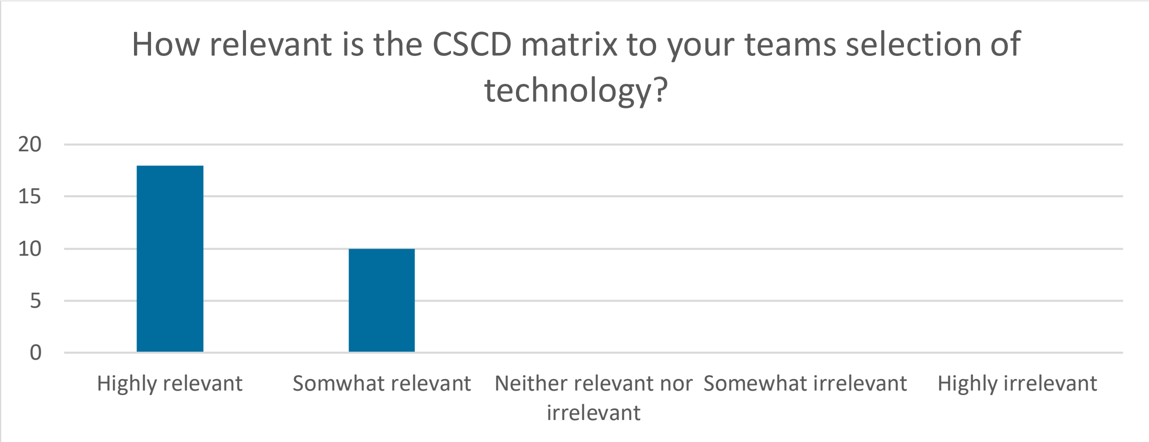

Figure 9 - Response to the survey question on the relevance of the CSCD matrix to students' education

The results for the student's understanding of the CSCD matrix (Figure 10) was highly mixed with the majority of students agreeing with a little help they could use the CSCD matrix (15 out of 28 students) and slightly fewer agreeing that with a lot of help they could use the CSCD matrix (8 out of 28 students). Although the majority felt they could use the CSCD matrix with little or no guidance, a considerable proportion would struggle to use it for their projects.

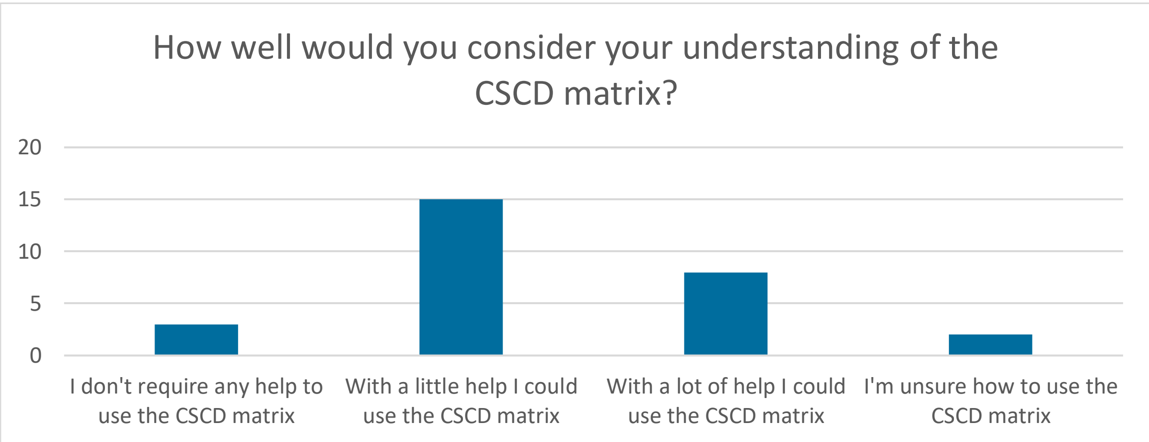

Figure 10 - Response to the survey question on how well the matrix is understood by students

Students shared reasons for the lack of understanding that were needed for further clarity including "matrix works but is somewhat hard to understand," particularly in the method of the CSCD matrix creation, "The purpose of the numbers on the sides of the matrix and how they are derived is unclear." Upon reflection, It was difficult for students to move from understanding collaboration requirements to applying them within the matrix.

Following the students' projects in 2018 a further survey was distributed, asking how students used the CSCD matrix. The following responses were the ways that the matrix was used "To evaluate technologies at the start of the project", "To identify the most appropriate technologies", "To overcome barriers when challenges arose due to technology use", "To ensure that the correct tools are used throughout the project" and "As a supportive tool to help the team discuss the available technologies."

There were several benefits observed in the workshops. The outcomes of discussions with the students identified problems that might impact CSCD education. Project-based learning is a well-established method of teaching, especially in building soft skills, and there appears to be a gap in the publication of reflections on the classroom to be shared and implemented in future classes. This type of collaboration would improve knowledge of the requirements of CSCD for all students to benefit. The approach of these workshops is to give students state-of-the-art information by reflecting on issues of the previous GDP year and other related classes. Students can then decide to engage and implement practices as they determine appropriate, and they are at least aware and prepared.

As students use the CSCD matrix to discuss implications for their projects, a student can apply their knowledge of technologies they are familiar with, functionalities they are familiar with and knowledge of the CSCD requirements. Students function as both the learner and the expert. This empowers the students to take responsibility for their learning experience to implement informed decision and creating protocols of working.

One unintended outcome was the student's reflection on their own performance towards the team's goals. Students of the GDP struggle to make comments on their own behaviours, however, the CSCD matrix is establishing a baseline in terms of the requirements of technology, and the student have been able to understand the human aspect in technology use. Critical analysis of oneself is essential for reflection and improvement for future projects.

With the benefits of the CSCD matrix established for inclusion within the online short course in CSCD, an investigation was established into the best way to present the matrix at an appropriate level of abstraction for final year students' education.

Feedback from the workshop in 2018 on difficulties understanding how to use the CSCD matrix was addressed by simplifying the activity. Rather than displaying the matrix with the full set of requirements for collaboration (19 in total), students were first given a CSCD matrix example with one requirement, one technology and five functionalities. Once they felt confident, students could progress to more complex versions of the matrix e.g., three technologies, six functionalities and six requirements. The rationale for this was to link with Mamo et al. (2015), who identifies the requirements of four technologies within student's collaborative design projects.

Students were introduced to the CSCD matrix (Figure 11) within the final lesson of the online short course that allows students to learn about collaborative requirements and reflect on the requirements before moving on to applying the knowledge within the CSCD matrix activity.

Students would have the ability to revisit earlier weeks if they struggled to consider the requirements. Once familiar with this simplified matrix, the students can move on to the full matrix, that could be used to complete their technology investigations towards technology selection as a team.

Technologies	Pick four technologies …							
		Technology Functionality	Pick six functionalities…					
CSCD Requirements	Communication	Describe the requirement …						
	Environment							
	Resources							
	Team							
	Process and Structure							
	Purpose							

Figure 11 – Simplified CSCD matrix for use by students during the online short course in CSCD

Feedback from the online course was used to evaluate how successful the CSCD matrix education was in the online format (Figure 12) and split into smaller lessons that build to the full matrix. 38 students responded to the feedback request. Half of the students agree that they did not require any help with using the matrix (19 out of 38 students) and their understanding was high. A minority said that with a little help they could use the CSCD matrix (16 out of 38 students) and slightly fewer agreeing that with a lot of help they could use the CSCD matrix (3 out of 38 students). This was a significant improvement on the workshops before.

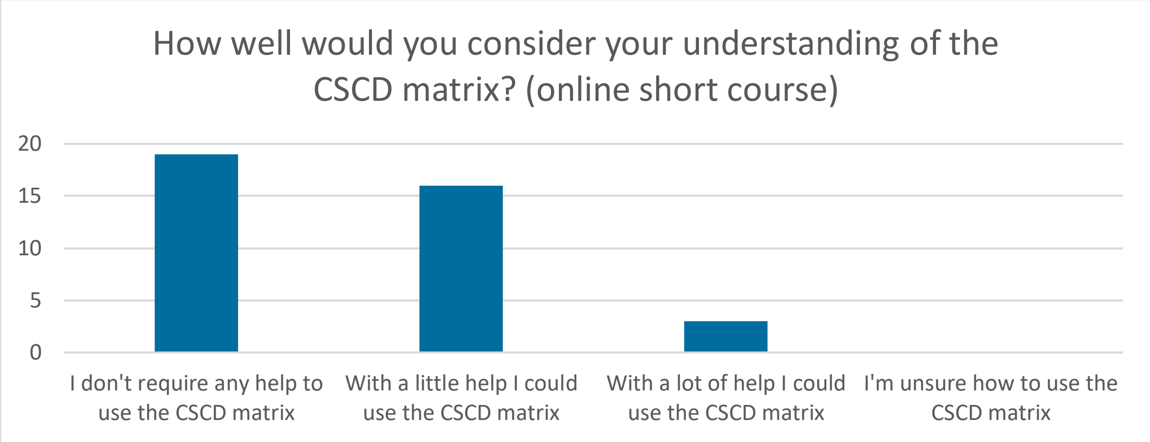

Figure 12 – Response to the survey question on the understanding of the matrix by students

Following the specific answers on the CSCD matrix, there were some general comments asking for more examples of projects in future versions of the course and to simplify the content further. Most students, 90% stated that the class has prepared them fully for the collaborative design projects with 10% stating they were somewhat prepared.

Discussion

In this section, the outcomes of supporting technology selection in collaborative engineering design student teams are discussed. First, there are insights following the identification of gaps in students' knowledge as part of the iterative development of the workshops. Secondly, the development of the online short course in CSCD led to insights for other educators developing similar courses both for discipline and also format. And finally, a discussion on the use of the CSCD matrix within an educational environment and an evaluation of its use within an educational context. Throughout the discussion section implications for policy, research, educational practice, or policy are discussed.

Gaps in students' knowledge

A motivation of the online course development was to fill gaps in students' knowledge about CSCD. By filling these gaps, students would be in a better position to conduct distributed collaborative design projects. Gaps in students' knowledge were identified through a literature review of collaborative engineering design and an educational workshop.

Almost all the gaps identified were not unique to CSCD and could be barriers in research on Computer Supported Collaborative Work (CSCW). However, there are key gaps in the context of design that make them unique to design.

Sharing rationale is difficult in a digital visual context as the tool used must allow for annotations to figures to share rationale and contextualise the drawings. This is used to highlight that what may be appropriate for one educational environment may not be appropriate for another.

Similarly, Different models of collaboration may be appropriate in a design project context that may not be appropriate in other educational domains. However, the topic is appropriate to consider as identifying appropriate models of collaboration is important to consider for all domains that are subject specific.

Emerging issues caused by technology use in design projects may highlight the current and future challenges of this generation of students and the next. Respect for others personal lives and workload was a key gap that highlights changing behaviours towards education where if one student feels they are available 24/7 then others could or should be also.

A key lesson from identifying gaps in knowledge and reflecting on teamwork practice is understanding that what is experienced within an educational environment is indicative of real-world practice. Reassurance that the same situations will arise when students move into industry jobs and having experience of how to overcome challenges is a lesson.

Case studies were used during all workshops, however, more examples and case studies were requested. Although learning of the requirements of collaboration was competent throughout, there is a gap in the student's ability to contextualise the knowledge within their own projects in which case studies can support their learning.

As workshops progressed and gaps were filled, the gaps identified in the later workshops were fundamentally different to those in the earlier workshops. Students identified practical gaps in knowledge early on including choosing appropriate technology, finding documents, file type compatibility and connection issues. However, these gaps were discussed in later workshops and ways of overcoming these gaps were suggested to students meaning the gaps had been filled. Gaps that remained included giving up control, aligning to the strengths of the team and skills gap that are more complex in nature to solve depending on aspects related to the individual team members and the requirements of the project. There is a depth in the gaps identified in the later workshops that require a deeper discussion about the challenges associated before solutions can be reached.

Gaps were communicated from one workshop to the next with the redesign of the introduction and concluding presentation slides. For example, Workshop 1 outcomes led to the inclusion of new material in workshop 2 in the introduction slides, specifically a slide and discussion on cultural differences in design teams and the benefits for global design. This was the same for workshops 3 and 4. The outcomes of workshop 4 were presented to workshop 5 in the form of virtual sticky-notes that were discussed with students.

Students were told that the previous studies took place after the workshop was complete. They were also introduced to the outcomes of the workshops as 'recommendations for future students' in concluding slides. This functioned as short interventions the teams could quickly act on within their teams.

Reflections on the development of an online short course in CSCD

The success of the method of development of the online short course in CSCD is prevalent in the response from students to the survey questions. It is important to preface any results around this time as being pre COVID-19 pandemic (September to December 2019) and to reflect that the students did not have exposure to online learning courses. All other aspects of the class where studio-based learning as a signature pedagogy in engineering design education is, however, the nature of global design is digital, and students' collaboration was almost always conducted online.

The process of iterative development has ensured an appropriate learning experience for students with the appropriate knowledge to complement their gaps in knowledge. This process is not dissimilar to the customary practice of iterative development of a module year on year based on student feedback. What is unique, is the focus on filling gaps in student knowledge based on the literature rather than an approach to satisfy student experience and introduce the latest knowledge into the classroom. Taking this approach has delivered a complete learning experience required by students for their global design projects.

It is expected that the approach will be interesting to others who are developing or who conduct regular global design classes and others who teach in the areas of distributed design or who are working to develop flipped classroom experience for students.

Students shared text feedback on aspects of the class which they thought worked well and other that they felt required further development. One student wrote "I found part 2 about the collaboration methods to be a bit confusing. The two models presented were not explained with enough detail … I did not find that the graphical representations explained the concepts very well and (I) was not able to find much information through the internet on each model." Reflecting on this student experience there are obvious nuances between lecture based and online learning. The online short course was designed to be completely asynchronous and self-led, so there was no opportunities for students to ask questions or clarify the learning experience. It is necessary even within these restrictions to have opportunities for questions and answers in the form of a forum or comments section. This required the teacher to have an active role in conducting the class that was not the intention due to the asynchronous nature of how students interact with the content. Alternatively, the lesson on collaborative models does not suit a digital environment as it is currently designed and requires further development.

Another student shared what could become a growing issue as more diverse students join the class related to terminology, more attention needs to be taken to clarifying the language used that may be completely unfamiliar to non-native English speakers. Words such as Asynchronous and synchronous, or collocated and distributed are not common terms.

A final comment from a student that would lead to improvements was "I was shocked to learn that students prefer video conference to audio conference. To me video is just pain to set up and does not add anything." This reflection highlights the importance of building an understanding of global design projects and managing the expectation of the students who engage in these classes. However, the course is not designed to support students to overcome their preconceived bias, in this case, stemming from cultural differences or personal experience. This has highlighted that the online short course method is not a replacement for monitoring or tutoring to encourage students to share personal reflections with each other and work to find a common ground. This may become a formal exercise as part of the course. Something that the reflective forums could not achieve.

Conclusion

This paper conveys the development of an online course in CSCD. The need for a course to support students' education on collaborative requirements, and technology evaluation and selection was established through observations of the Global Design Class and changes in technology over time from the literature. To support this development, literature on pedagogical considerations of course development was identified to establish a suitable methodology. To ensure the workshops and later online course were fully considerate of the requirements of modern students, three research questions were established: What are the challenges in design practice for collaborative engineering design teams that technology influences?, What are the gaps in knowledge that students have, that can be filled by the literature?, and Can these gaps in knowledge be filled with a designed educational intervention? The methodology chosen was the development of a workshop and iterative development of workshops over time to ensure student's gaps in knowledge on CSCD were filled and fully considered for a robust course.

The workshop was designed with multiple parts, an introductory lecture on CSCD, an activity on the challenges and how to overcome challenges of CSCD and concluding slides to summarise the outcomes. The activity of the workshop was designed to ensure robust student reflection on the challenges of CSCD and to inform the educators of the gaps in students' knowledge. Future workshops would develop with an expanded introductory lecture and discussion based on the previous identified gaps.

The workshops took place over three years with students of two universities and two different global design classes. Teams of students worked together to identify the challenges and how to overcome challenges. In total 125 students took part.

To build the first lecture, literature was used on challenges of collaborative global design or recommendations to inform students of best practices. Moving forward, gaps in knowledge from the workshops from previous workshops were added to the next workshop lecture and discussion around the topic supported understanding. As the workshops progressed the observations of the educators in the class were that the gaps in knowledge were becoming of a higher abstraction level and less practical, and the number of gaps was decreasing, supporting the methodology of the workshop development. Gaps in knowledge such as how to deal with cultural differences and techniques and tools to do so were replaced with personal reflections on a designer's ability to give up control for a design's development as part of a design team when appropriate.

Following the creation of a robust version of this workshop, the knowledge and understanding of student's requirements were transferred to an online short course enabling all students in the global projects to take part. The online context of the course prepares students for group projects by giving them an experience of learning and collaborating online. The knowledge taught during the short online course includes known gaps in students' knowledge based on previous workshops.

The class was developed on NEO LMS for practical reasons and full consideration was given to the experience of learning online compared with in person using pedagogical frameworks, such as (Salmon, 2013). The online short course encourages students to reflect on their answers to key questions about the challenges and overcoming challenges of global collaboration.

The developed online weeklong class is independent of the Global Design Project. Students are encouraged to engage with the content across three separate days to encourage reflection using forums and questions. The online course reflects the success of the workshops with introductory lectures, reflection on challenges of CSCD and how to overcome challenges and recommendations for students to implement. With minor modifications, it can be developed for a more generic audience. This novel class has been prepared for a higher education audience however it can be adapted for different disciplines and education levels.

The method of the course development has proven successful in the creation of a robust learning experience. Students have responded that they feel prepared for the Global projects by taking part in the online course in their ability to select suitable technology that requires a robust knowledge of CSCD. Feedback for improvement was limited and will be considered for future versions of the course.

The CSCD matrix was used to help answer RQ3. As a design intervention to support technology evaluation and selection. Feedback on the CSCD matrix was positive, and with perhaps an indication that there is development required to the online course to fully support comprehension of the method and how to use it. However, students understand that the tool is highly relevant to their education.

The paper summarises the gaps in knowledge of the students along with reflections on the development of the short course moving forward and for others who are considering the development of similar courses. The authors are interested in re-examining the course design and development post-covid to identify any changes that were required in the design of the course to better support students working remotely. The course is available to all who would be interested in implementing it as part of their modules.

Acknowledgements

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References

Anderson, L. W., Krathwohl Peter W Airasian, D. R., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C. (2001). A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives. Pearsons Education.

Andert, D., & Alexakis, G. (2015). Virtual Teaming and Digital Learning Strategies: Preparing Students for a Global Workplace. MERLOT Journal of Online Learning and Teaching, 11(1), 146–172.

Balamuralithara, B., & Woods, P. C. (2009). Virtual laboratories in engineering education: The simulation lab and remote lab. Computer Applications in Engineering Education, 17(1), 108–118. https://doi.org/10.1002/CAE.20186

Bednar, A. K., Cunningham, D., Duffy, T., & Perry, J. D. (1992). Theory into practice: How do we link. In T. M. Duffy & D. H. Jonassen (Eds.), Constructivism and the technology of instruction: A conversation (1st ed.). Routledge. https://doi.org/10.4324/9780203461976

Beetham, H., & Sharpe, R. (2019). Rethinking pedagogy for a digital age: principles and practices of design (3rd ed.). Routledge. https://doi.org/10.4324/9781351252805

Bohemia, E., & Ghassan, A. (2012). Globally Networked Collaborative Learning in Industrial Design. American Journal of Distance Education, 26(2), 110–125. https://doi.org/10.1080/08923647.2012.663678

Brisco, R., Whitfield, R. I., & Grierson, H. (2016). Recommendations for the use of social network sites and mobile devices in a collaborative engineering design project. Proceedings of the 18th International Conference on Engineering and Product Design Education (E&PDE2016).

Brisco, R., Whitfield, R. I., & Grierson, H. (2017). The use of social network sites in a global engineering design project. Proceedings of the 21st International Conference on Engineering Design (ICED17), 9.

Brisco, R., Whitfield, R. I., & Grierson, H. (2018). Are social network sites the future of engineering design education? DS 93: Proceedings of the 20th International Conference on Engineering and Product Design Education (E&PDE2018), 400–405.

Brisco, R., Whitfield, R. I., & Grierson, H. (2020). A novel systematic method to evaluate computer-supported collaborative design technologies. Research in Engineering Design, 31(1), 53–81. https://doi.org/10.1007/S00163-019-00323-7

Christie, M., & de Graaff, E. (2016). The philosophical and pedagogical underpinnings of Active Learning in Engineering Education. European Journal of Engineering Education, 42(1), 5–16. https://doi.org/10.1080/03043797.2016.1254160

Dewey, J. (1910). How We Think. In D.C. Heath & Co (Vol. 1). D.C. Heath & Co.

Emami, M. R. (2009). Application of learning models to the engineering design pedagogy. ASEE Annual Conference and Exposition, Conference Proceedings, 14.220.1-14.220.16. https://doi.org/10.18260/1-2--5315

Ertmer, P. A., & Newby, T. J. (1993). Behaviorism, Cognitivism, Constructivism: Comparing Critical Features from an Instructional Design Perspective. Performance Improvement Quarterly, 6(4), 50–72. https://doi.org/10.1111/J.1937-8327.1993.TB00605.X

Evans, M. A., & Pei, E. (2010). iD Cards. https://www.idsa.org/sites/default/files/IDSA%20iD%20Cards.pdf

Fleischmann, K. (2020). Online design education: Searching for a middle ground. Arts and Humanities in Higher Education, 19(1), 36–57. https://doi.org/10.1177/1474022218758231

Fruchter, R., Bosch-Sijtsema, P., & Ruohomäki, V. (2010). Tension between perceived collocation and actual geographic distribution in project teams. AI and Society, 25(2), 183–192. https://doi.org/10.1007/S00146-009-0254-X

Gopsill, J. A. (2014). A Social Media Approach to Support Engineering Design Communication — the University of Bath's research portal. University of Bath.

Gopsill, J. A., McAlpine, H. C., & Hicks, B. J. (2015). Supporting engineering design communication using a custom-built social media tool – PartBook. Advanced Engineering Informatics, 29(3), 523–548. https://doi.org/10.1016/J.AEI.2015.04.008

Grierson, H. (2010). Towards Principles and Project Memories for Distributed-Design Information Storing in Engineering Design Education. University of Strathclyde.

Hurn, K. (2012). The impact of social software in product design higher education. Design and Technology Education: An International Journal, 17(2), 35–48.

Hussain, Y. A., & Jaeger, M. (2018). LMS-supported PBL assessment in an undergraduate engineering program—Case study. Computer Applications in Engineering Education, 26(5), 1915–1929. https://doi.org/10.1002/CAE.22037

Kinzie, J., & Kuh, G. D. (2004). Going Deep Learning from Campuses that are Responsibility for Student Success, 9(5), 2–8. https://doi.org/10.1002/ABC.105

Klimova, B. (2016). Benefits and limitations of social network sites for engineering education - A review study. IEEE Global Engineering Education Conference, EDUCON, 10-13-April-2016, 53–56. https://doi.org/10.1109/EDUCON.2016.7474530

Kolb, D. A. (1984). Experiential learning: experience as the source of learning and development. Prentice-Hall.

Kovacevic, A., Howell, B., Jagadeesh, C., Read, M., Horak, P., Tarnok, Z., Hazen, G., & Leto, A. (2018). Application of “CODEVE” methodology in transatlantic student design project. DS 93: Proceedings of the 20th International Conference on Engineering and Product Design Education, 242–247.

Smart, K.L., & Cappel, J.J., (2006). Students’ Perceptions of Online Learning: A Comparative Study. Journal of Information Technology Education: Research, 5, 201–219. https://doi.org/10.28945/243

Ledwith, M. (2017). Emancipatory Action Research as a Critical Living Praxis: From Dominant Narratives to Counternarrative. In L. Rowell, C. Bruce, J. Shosh, & M. Riel (Eds.), The Palgrave International Handbook of Action Research (pp. 49–62). Palgrave Macmillan. https://doi.org/10.1057/978-1-137-40523-4_4

Luo, L. (2019). Analysis on Online and Offline Blended Teaching Design Taking “Engineering Survey” Course of Non-surveying and Mapping Engineering Specialty as an Example. Proceedings of the 3rd International Conference on Culture, Education and Economic Development of Modern Society (ICCESE 2019), 995–999. https://doi.org/10.2991/ICCESE-19.2019.218

Mamo, J., Farrugia, P., Borg, J., Wodehouse, A., Grierson, H., & Kovacevic, A. (2015). Using engineering design tools in multidisciplinary distributed student teams. DS 82: Proceedings of the 17th International Conference on Engineering and Product Design Education (E&PDE15), 99–104.

Núñez-Andrés, M. A., Martinez-Molina, A., Casquero-Modrego, N., & Suk, J. Y. (2022). The impact of peer learning on student performance in an architectural sustainability course. International Journal of Sustainability in Higher Education, 23(1), 159–176. https://doi.org/10.1108/IJSHE-11-2020-0447

Qiu, R. G. (2019). A systemic approach to leveraging student engagement in collaborative learning to improve online engineering education. International Journal of Technology Enhanced Learning, 11(1), 1–19. https://doi.org/10.1504/IJTEL.2019.096734

Salmon, G. (2013). E-tivities. Routledge. https://doi.org/10.4324/9780203074640

Schunk, D. H. (2011). Self-Efficacy and Academic Motivation. Educational Psychologist, 26(3–4), 207–231. https://doi.org/10.1080/00461520.1991.9653133

Sclater, N. (2008). Web 2.0, Personal Learning Environments, and the Future of Learning Management Systems. EDUCAUSE, 2008(13).

Sezgin, S., & Sevim Cirak, N. (2021). The role of MOOCs in engineering education: An exploratory systematic review of peer-reviewed literature. Computer Applications in Engineering Education, 29(4), 950–968. https://doi.org/10.1002/CAE.22350

Sielmann, C., Keulen, C., & Hu, S.-F. (2021). Multi-campus teaching in a Canadian engineering context: assessing presence using the COI survey. Proceedings of the Canadian Engineering Education Association (CEEA). https://doi.org/10.24908/PCEEA.VI0.14878

Sole, M. E., Barber, P., & Turner, I. (2021). Mechanical engineering design, learning from the past to design a better future? Design and Technology Education: An International Journal, 26(3), 178–189.
Stange, M. (2020). Preparing Students for Digital Era Careers. Inquiry: The Journal of the Virginia Community Colleges, 23(1).
Tang, H. H., Lee, Y. Y., & Chen, W. (2012). Re-examining the relationship between design performance and the design process using reflection in action. AI EDAM, 26(2), 205–219. https://doi.org/10.1017/S0890060412000078
Thornton, P. B. (2013). Reflections on helping students learn. In Thriving in academe: Reflections on helping students learn.
Williams, M. (2017). John Dewey in the 21st Century. Journal of Inquiry and Action in Education, 9(1), 91–102.
Yang, N. bin. (2010). Applying project-based learning to product design teaching. Proceedings - 2010 International Conference on System Science, Engineering Design and Manufacturing Informatization, ICSEM 2010, 1, 171–173. https://doi.org/10.1109/ICSEM.2010.52
Yu, M., Xu, T., Gao, J., Yu, R., Deng, R., Liu, Y., Zhang, Y., & Feng, S. (2018). Research on integrating online learning into offline teaching. 13th International Conference on Computer Science and Education, ICCSE 2018, 441–445. https://doi.org/10.1109/ICCSE.2018.8468738

Developing spatial literacy through design of built environments: Art and crafts teachers' strategies

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Abstract
Designing built environments demands the ability to make translations between your visions, visual representations of these, and the full-scale environment that is to be built. Pupils working on architectural tasks face these challenges of translation. How can the teacher come to their aid? Research on teaching strategies for the architectural studio has sought to articulate the entire design process, something that leads to overarching strategies but less hands-on, detailed descriptions. This article offers greater in-depth insight into the strategies teachers use to enhance pupils' spatial literacy. In semi-structured interviews, six lower secondary school *Art and crafts* teachers described their teaching practice related to architectural tasks. From the teachers' detailed moves, we have identified five teaching strategies and placed them in a visual model that demonstrates what role they may play in aiding pupils in the process of designing built environments. By articulating these strategies, we hope to contribute to the development of the vocabulary used in and about teaching design and architecture.

Keywords
Art and craft education, Architecture education, Spatial literacy, Design process

Introduction
Our built environments surround us and affect our everyday lives. Designing and planning built environments in compulsory education is therefore relevant for more than aspiring architects. In designing built environments, children and youths can develop general life skills that are useful in planning, redecorating or choosing private housing. In addition, it enables children and youths to become engaged, critical, and knowledgeable citizens who can participate in democratic processes (Nielsen & Digranes, 2007) regarding our built environments.

The new Norwegian national curriculum for primary and lower secondary education was implemented in August 2020. The subject *Art and Crafts* is compulsory across Years 1 to 10 and is the fifth most comprehensive subject in primary and lower secondary education. After Year 10, pupils are expected to be able to sketch and model new solutions for their local built environment (The Norwegian Directorate for Education and Training, 2020a). This is a tall order for youths aged 15–16, as it has been found to be challenging for adults too. Observing the interaction between an architect and two clients while planning a residential building, Nielsen (2000) found that the clients understood the architectural drawings only to a certain extent and had difficulties imagining the spatial properties of the finished building. Another example of the challenge of interpreting drawings is found in the building of a centrally located hotel in Oslo, the Thon Hotel Opera, in 2000. The hotel was criticised as being too tall, creating a wall in front of the Opera building (Neubert, 2007). The politicians behind the decision had not fully comprehended the drawings and stated that they would not have consented to the plans if they had understood their implications (Lundgaard, 2000; Nielsen, 2004). The ability to read visual representations and imagine them as finished buildings, as well as shifting between different scales while designing, are components of spatial literacy. The above-mentioned aims in the curricula are intended to develop pupils' spatial literacy through the subject *Art and Crafts*. However, because the skills involved are difficult to demonstrate or explain, it is important to examine how they can be taught. This article aims to describe strategies used by lower secondary school teachers to enhance their pupils' spatial literacy and to further develop the vocabulary used in teaching design and architecture. As there is little research on how this topic is taught in lower secondary school *Art and crafts*, we present how learning is facilitated in higher education.

Facilitating learning in the architectural studio

Teachers in architectural studios have been criticised for not articulating the design process to their students (van Dooren et al., 2019; Taneri & Dogan, 2021). They comment on the students' products but do not give a sufficient explanation of how the process should be conducted. Taneri and Dogan (2021) link this to a learning-by-doing approach that emphasizes implicit learning acquired while working on design tasks, while van Dooren and colleagues (2019) explain that this reflects a traditional lack of a shared vocabulary and that the teachers are expert architects – not trained teachers. Yorgancioğlu and Tunali's (2020) research on the pedagogic identities of tutors and students in the design studio corroborates the image of students learning through practical work, while the tutors critique the products in one-to-one dialogues with the students. They suggest that tutors shift their roles as "a source of 'expertise' or 'authority'" (Yorgancioğlu & Tunali, 2020, p. 29) to being facilitators of peer critique among students to engage the students more in the learning process. However, peer critique does not help students untangle the difficult design process, as the products are the focal points for these too, nor does it address teaching strategies.

Research aiming to develop strategies for teaching design has been mostly developed within the context of higher education (McLaughlan & Chatterjee, 2020; Shanthi Priya et al., 2020; Van Dooren et al., 2019). Of these, only McLaughlan and Chatterjee (2020) explored existing teaching practices, while the other two explored the implementation of teaching methods constructed theoretically. Regarding classroom practices as unique resources for developing educational research, while identifying a research gap here, we have chosen an approach empirically based on descriptions of teaching practices. Pupils in lower secondary schools demand more explicit, step-by-step guidance through the design process, as opposed to architecture and design students. In addition, lower secondary school teachers often have a solid pedagogical foundation. This creates both the need and the conditions for developing suitable approaches to enhance pupils' spatial literacy through designing built environments. An exploration of these teaching strategies could contribute to developing education in both the subject of *Art and crafts* and the architectural studio.

Spatial literacy: Moving from cognitive processes to complex practical tasks

Spatial skills are useful in everyday activities, such as manoeuvring a car or rearranging furniture (Sutton & Williams, 2011), orienting yourself in an environment (Ishikawa, 2021), or choosing the shortest route home (Nielsen, Oberle & Sugumaran, 2011). In architecture, engineering, design and technology, spatial skills are especially important (Buckley et al., 2022;

Ilić & Đukić, 2017; Lane et al., 2019; Lehtinen et al. 2021; Liao, 2017; Ramey & Uttal, 2017; Sutton & Williams, 2011). For example, the ability to understand the relationship between two-dimensional representations and three-dimensional objects, which is an implicit part of spatial skills (Lohman, 1979; Macnab & Johnstone, 1990; Sutton et al., 2005), is essential in interpreting architectural drawings.

There are no clear definitions of spatial skills, and the terms spatial skills and spatial abilities are often used interchangeably (Berkan et al., 2020; Heil, 2019; Ilić & Đukić, 2017; Sorby, 1999). Two seminal definitions of spatial skills commonly used are the ability to mentally manipulate, rotate, twist, or invert objects (McGee, 1979) and "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1996, p. 98). Meanwhile, empirically proven theories on cognitive abilities describe spatial abilities as a constellation of factors. The most updated framework, the Cattell-Horn-Carroll (CHC) theory, is not an absolute model; additional factors have been suggested (Buckley et al., 2018). Examples of factors relevant to designing built environments are *Visualisation*, "the ability to perceive complex patterns and mentally simulate how they might look when transformed (e.g. rotated, changed in size, partially obscured)," *Length estimation,* and *Imagery*, the "ability to produce very vivid images" (Schneider & McGrew, 2012, cited in Buckley et al., 2018, p. 953). While these theories seek to define spatial skills as internal cognitive processes, *spatial literacy* also concerns the use of spatial skills in complex, practical tasks (Lane et al., 2019). Moore-Russo and colleagues (2012, p. 98) describe a spatially literate person as able to "(a) visualize spatial objects; (b) reason about properties of and relationships between spatial objects; and (c) send (and receive) communication about spatial objects and relationships." This demands well-developed spatial skills but also the ability to convey them in complex tasks involving others. In a study conducted by Ramey and Uttal (2017), participants in a middle school summer engineering camp were found to use both internal cognitive processes and thinking with external objects and spatial representations, such as gestures, while collaborating in hands-on engineering activities. While it is relevant to understand the internal cognitive processes linked to spatial skills, the term *spatial literacy* is most suitable in this investigation into the design of built environments due to the practical, hands-on work in materials associated with the *Art and crafts* subject.

Designing built environments entails a translation from the abstract into the concrete. One goes through a process of visuospatial abstraction, imagining what is to be built, design conceptualisations through two-dimensional drawings, and digital and analogue three-dimensional models, all of which are related to a concrete product in full scale (Bhatt & Schultz, 2017). To illustrate this process, we developed the model shown in Figure 1, to be used as a framework for further discussion.

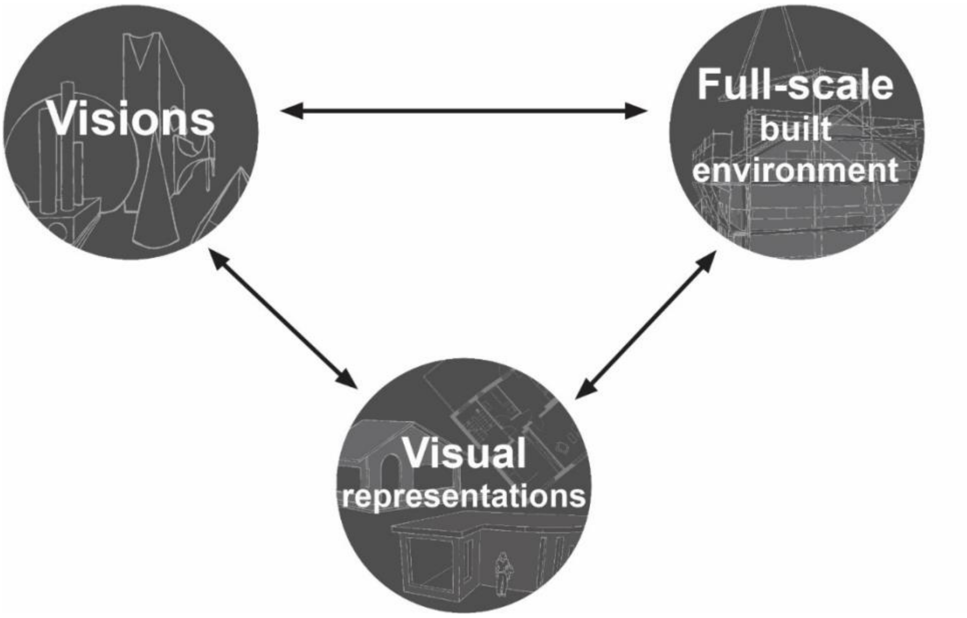

Figure 1. A visualisation of the relationship between different levels of abstraction and scale involved in the process of designing built environments.

Visions are abstract ideas and plans, *visual representations* include drawings and models, and the *full-scale built environment* represents the finished room, building, or other architectural product. The bidirectional arrows indicate the shifting between these three properties throughout the process. This translation between visions, visual representations, and full scale in educational activities is our main interest in this article.

Spatial skills are malleable and can be developed through relevant educational activities (Uttal et al., 2013). Berkan and colleagues (2020) noted significant progress in architecture students' spatial skills after completing a first-term introductory course on the architectural design process. Julià and Antoli (2016) conducted an educational robotics course aimed at improving 12-year-olds' spatial skills through practical hands-on learning. After 10 one-hour sessions, the children's spatial skills improved. Spatial development also occurs as children mature, according to Piaget. Pupils in lower secondary school, ages 13–16, are at the stage of mastering the ability to switch between two and three dimensions, understand area, volume, distance, translation, rotation, and reflection, and combine measurement concepts with projective skills (Piaget & Inhelder, 1956). Unfamiliar or moving objects can be difficult for these youths or even older people to visualise (Sorby, 1999). This makes it especially valuable to investigate how lower secondary school teachers work to enhance their pupils' spatial literacy.

Research questions and aims

In this article, we seek to answer the following research question:

> *Which strategies are used by Art and crafts-teachers to enhance their pupils' capacity to translate between visions, visual representations, and full-scale in designing built environments?*

In this article, strategies are directly linked with actions: “a broad brush depiction of plans – of what should be done to achieve certain objectives” (Goodyear, 2005, p. 87). Strategies are understood as descriptors of what teachers do to facilitate learning. The term refers to both planned procedures and moment-by-moment activities engaged in by teachers and students (OECD, 2010) during supervision. The aim is not to recommend one strategy. As Marzano (2007) points out, research will never be able to identify strategies that work with every student in every class. The individual teacher must determine which strategy to employ depending on the singular situation, and our contribution is to showcase and discuss a broad range of available strategies.

Methods

A qualitative method of semi-structured interviews was used to construct the main data for this article. While describing the teachers’ strategies, corresponding episodes from fieldwork in lower secondary education are added. These episodes were captured using participant observation and semi-structured group interviews.

Semi-structured interviews with teachers

Six participants were purposively sampled (Bryman, 2016, p. 410) for the interviews. The sampling was guided by the following criteria: *Art and crafts* teachers in lower secondary school with relevant education, as well as experience with and a special interest in using architectural tasks in their teaching. Potential participants were identified in two ways: (1) as authors of *Art and crafts*-related texts found in searches in a non-academic journal and an open national base of educational resources, and (2) through inquiries within our professional network. This led to the identification of 10 teachers who received a request to participate in a research interview, followed by one reminder. Six responded positively and participated in interviews conducted by the first author.

The participants’ teaching experience ranged from 3 to 20 years. All taught at the lower secondary level, with pupils aged 13–16, in public schools at the time of the interview. Teaching competencies in *Art and crafts* can be achieved in several ways, such as through specialised teacher education or art education combined with pedagogy. For anonymisation considerations, the individual teachers’ education will not be described, but all six had at least 60 ECTS, the equivalent of a full year of study, of specialisation in the subject.

The interviews were semi-structured (Brinkmann & Kvale, 2015, pp. 31–32), lasted between 50 and 70 minutes and were conducted via video conference in December 2020–January 2021. In the interviews, the teachers were asked to describe one or more architectural assignments they regarded as successful (presented in Table 1), and to elaborate on the active moves they employed to enhance their pupils’ spatial literacy. The interview guide used for the interviews is included in Appendix A. The interviews provided the teachers’ own narrative of what they considered important rather than their exact teaching practice. Although this could be considered a weakness (Jerolmack & Khan, 2014), in this study we view it as a strength, as our interest lies in the moves and actions regarded as most successful rather than the most common. Another potential weakness is that participants may adapt their statements to please the researchers (Brinkmann & Kvale, 2015, p. 38). Asking them to describe their actual practices, rather than an ideal approach or discussing more value-laden questions, is thought to help mitigate this weakness. One final note on the method’s limitations regards the concept of data saturation (Cohen et al., 2018, pp. 222–224). As all interviews were scheduled in advance, we did not attempt to reach saturation, which means that new participants might have provided new perspectives. However, a noticeable overlap across all interviews suggests that the results are trustworthy.

Table 1. Overview of architectural assignments, as described in teacher interviews (names are pseudonyms)

	Assignment	Phases	Level	Time frame
Alexander	Design a holiday home of 100 m^2. Focus on exterior, with the option of decorating the interior.	1. Open exploration with different digital and analogue techniques 2. 3D-modelling in Ludenso, ending with an AR experience viewing the models in life-size 3. Cardboard model in 1:50 scale	Year 10	About 15 weeks
Birgitta	Design a small cabin of 30 m^2 with an innovative exterior and functional interior.	1. Form experiments in SketchUp, composing three blocks of differing character 2. Individual modelling of the cabin in SketchUp 3. Working in groups to make a floor plan and cardboard model based on one group member's ideas	Year 9	About 3 months
	Plan a remodelling of the school.	1. Needs analysis of the school 2. Sketching over existing floor plans and making drawings 3. 3D-modelling in SketchUp	Year 9	12–15 weeks
Christine	Design a house suitable for a figure 1- or 2-cm tall; work only on the exterior.	1. Practice cutting and gluing a pre-drawn house to learn how to make three-dimensional shapes 2. Cardboard model 3. Urban planning, placing the models together, thinking about location according to function	Year 8	Starting with one full day, adding as much time as needed
Danielle	Design the interior of a studio for a chosen artist, area based on the artists' needs.	1. Drawing the studio in one-point perspective 2. Floor plan 3. Cardboard model in 1:40 scale	Year 8	About 10 weeks
Elise	Design a small cabin of 18 m^2. Focus on an experimental shape of the building.	1. Open exploration with different digital and analogue techniques. Pupils were assigned a random geometric shape as a starting point and further challenged to move, remove, or double the shapes.	Year 10	About 8 weeks

		2. Three-dimensional "paper sketches" or prototypes in thin paper 3. Cardboard model in 1:25 scale 4. Poster where the model is edited into the assigned plot of land		
Frida	Design a "writing cabin" of 8 m^2. In the modelling, the focus was on the exterior. Project in the elective subject *Technology in practice.*	1. Idea phase with sketching and modelling in SketchUp 2. Floor plan 3. Model in scale, made of wood with electrical components	Year 8–10 mixed	About 19 weeks

Data analysis

Recorded interviews with teachers were transcribed by the first author, which may be viewed as the analysis's first step (Langdridge, 2006, p. 261). This was followed by a collective qualitative analysis in four steps (Eggebø, 2020). Although Eggebø (2020) inspired its collective form, our analysis also drew on the thematic interview analysis described by Langdridge (2006, pp. 262–267) and King & Horrocks (2010, pp. 152–158).

1. *Collective review of the data material*, in which we discussed each interview. In preparation for this step, we read the transcripts separately, and the first author wrote a summary of each interview. The aim of this step was to become familiar with the informants and the narratives in their interviews.
2. *Collective coding:* In this step, we used a web-based interface emulating a board with Post-it notes. Working separately but on the same board, we wrote descriptive codes that labelled the teachers' mentions of actions and moves in the transcripts, such as "make a cardboard model" or "start with 3D paper sketches." The summaries were checked towards the end to ensure that no important points were lost, as the aim was to include all approaches mentioned by the teachers.
3. *Grouping of themes* entailed moving the Post-it notes around to group the related codes and identify patterns across the interviews. Overlapping codes were removed and similar codes were combined. After identifying the initial groups, a descriptive headline for each group was created, leading the coding process into interpretive coding. This step was conducted in three rounds in which we thoroughly discussed what each code entailed, which codes should be grouped and the rationale behind the grouping. This step led to 10 initial groups that were further combined and restructured into five strategies. The above examples of codes were grouped under "Physical experiments", which is a part of the strategy "Encouraging three-dimensional visualisations".
4. *Outline of the text and plan for further work*: As the strategies began to evolve, we created an outline of the text and planned the writing process. The first author was responsible for writing, with comments and edits from the second author. Some sections were written collaboratively.

Corresponding episodes from fieldwork in Year 10 *Art and crafts*

Concurrent with carrying out and analysing the interviews, we conducted fieldwork at a Norwegian public school where pupils worked on an architectural assignment in Year 10 *Art and crafts*. While these pupils had no relation to the interviewed teachers, we recognised several of the approaches described by the teachers when observing how the pupils handled the challenges in the assignment. To deepen our understanding of the strategies and showcase their relevance in learning, we included corresponding episodes from this fieldwork. The episodes are not used to validate or revise the identified strategies but to show how the perspectives of teachers and pupils align. This strengthens the strategies' credibility and relevance.

The fieldwork was carried out in August 2020–May 2021. The pupils worked on an architectural assignment developed by the second author, who was a teacher at the school. During nine two-hour lessons, they designed a 50–120 m^2 building with a function of their own choice. After deciding on a concept and drawing a floor plan, the pupils made models of their buildings using either Lego, cardboard, Minecraft or SketchUp. The study methods used were participant observation (Cohen et al., 2018, pp. 551–555) and semi-structured group interviews (King & Horrocks, 2010, pp. 61–72). The first author was primarily a partially participating observer (Bryman, 2016, p. 436), but was also the responsible teacher in some lessons. After each lesson, the first author wrote field notes from interesting interactions narrated as episodes (Emerson et al., 2011, pp. 77–79). Included in these are notes from informal unstructured interviews (Bryman, 2016, p. 467) with some of the pupils. In addition, 24 of the 90 pupils chose to participate in semi-structured interviews of 10–30 minutes conducted in groups of 2–4.

After identifying the five strategies described by the teachers, we searched the field notes and interview transcripts for similar approaches used by the pupils participating in our fieldwork. The corresponding episodes are presented at the end of the description of each strategy.

The teachers' strategies

The teachers' projects exhibited a wide variety in terms of procedure, focus and duration, as described in Table 1. Some teachers, such as Christine and Elise, focused on creativity and experimenting with architectural styles and shapes, while others, such as Birgitta and Danielle, focused more on functionality and realistic measurements. The pupils of Alexander, Birgitta and Frida worked for quite a long time on a project consisting of several parts, while the project of Christine was shorter and focused on a cardboard model. Nevertheless, there are many parallels in their approaches to enhance their pupils' capacity to translate between visions, visual representations and full scale while designing built environments. Five strategies (Fig. 2) were identified through the analytical process of assigning descriptive codes to the teachers' detailed moves and actions and grouping them according to theme. The teachers' actions and moves are presented as part of the description of the strategies.

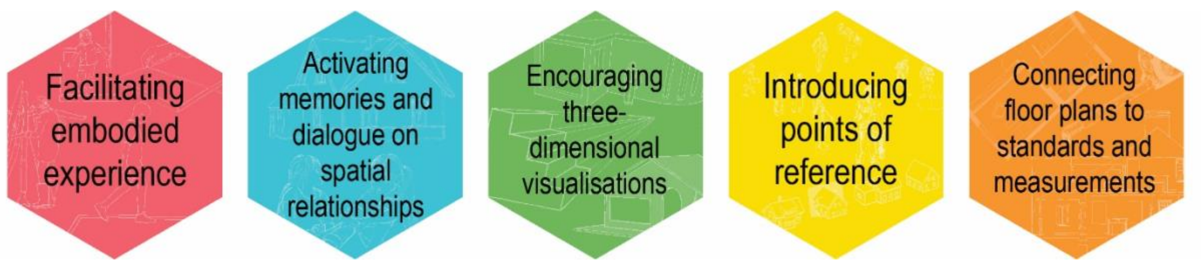

Figure 2. The interviewed teachers employed these five strategies: Facilitating embodied experience, Activating memories and dialogue on spatial relationships, Encouraging three-dimensional visualizations, Introducing points of reference, and Connecting floor plans to standards and measurements.

All these strategies were used by at least five or all six of the teachers, albeit to varying degrees, and are presented in depth below. Descriptions of the strategies are followed by corresponding episodes that illustrate how the pupils observed in our fieldwork used a similar approach.

Facilitating embodied experience

This strategy entails gaining an understanding of spatial properties through bodily interactions with full-scale environments. This strategy was used by all teachers except Christine.

In an exercise conducted by Birgitta, Elise and Frida, the class measured a given area and marked it with tape on the floor (Fig. 3), alternatively with pupils standing to mark each corner. They were encouraged to move around and experience this area to get an initial feel for the area in which they would work. Elise asked her pupils to plan their buildings from a plot of land they could visit. This was something that Alexander had not done, but stated that it would be ideal to provide such a concrete experience.

Figure 3. Marking the outline of a building with tape. Pupils are standing within the marked area and standing or lying in place of furniture. Photo by the second author.

Another approach to embodied experience mentioned by Alexander and Danielle was to measure the classroom and compare its size to the area of the assignment. Several teachers mentioned that pupils became curious about floor-to-ceiling height, the height of doors, and other dimensions in the classroom. Alexander stated that he always keeps a measuring tape in his desk for this purpose. Birgitta and Elise said that they told pupils to measure it themselves when asked about the size of an item.

Understanding spatial properties in relation to one's own body is significant, in Elise's opinion. She used the example of designing a bench or stairs and described instructing pupils to determine suitable measurements by measuring the chair they were sitting on or their own legs. Frida instructed pupils to look around and take measurements in relation to their own height, such as standing in the doorway and measuring it. During her interview, Birgitta expressed the importance of this strategy: “In working with spatial properties, there must be physical examples one can relate to. One can have an embodied experience with them. I believe that’s important.”

Corresponding episodes related to the strategy

Many of the observed pupils used measurements in the classroom to orient themselves. One, planning to add a pool, discussed with his fellow pupils whether a four-meter pool would be too long. Upon hearing this, the teacher pointed out that one of the walls of the room was four meters long, enabling the pupil to make a design decision. Another pupil related in the interview that after the teacher said the door was one meter wide, she began to imagine all the measurements in different numbers of doors. Yet another said that the teacher helped him measure the classroom at the beginning of the project “to put things into perspective,” as he said. While planning his project, he was able to relate it to the area of the classroom when considering how large an area he needed. A fourth pupil was observed estimating distances in the classroom with paces. He stated that this was helpful while drawing furniture into the floor plan, as judging from how the classroom was furnished within a similar area helped him imagine how much would fit and how large it all was.

Activating memories and dialogue on spatial relationships

This strategy relies on pupils’ reflections and mental visualisations. The teachers conducted whole-class dialogues or individual dialogues regarding spatial properties. These gave teachers the opportunity to activate the pupils’ memories of familiar houses and rooms. Some pupils became curious about the size of their own rooms, measured them at home and used this knowledge in their design process. Birgitta explained that while working with the floor plan of their school, her pupils understood the scale of the floor plan when they recognised the gymnasium. Imagining the size of a familiar room put the scale of the whole floor plan in context. “So, the fact that they can relate to, that they have been to the places they are talking about or that they have experienced it physically, these exact sizes, I think that is of great importance,” Birgitta said. Elise and Frida had also asked their pupils to design their buildings for specific and familiar plots of land in the school’s vicinity.

Most teachers also presented examples that their pupils were unfamiliar with and showed pictures and drawings for inspiration. Both Alexander and Danielle told their classes the size of their own apartments to exemplify how much you can fit into a certain area.

Corresponding episode related to the strategy

One of the observed pupils struggled to find a suitable area for his building and started over a few times. It all fell into place when he decided to combine rooms of 20 m^2, which was the area of his living room at home. Connecting the project to a familiar room helped him understand the area in which he was working. “Then I knew that all the rooms would be large enough,” he said in the interview.

Encouraging 3D-visualisations

Three-dimensional visualisations of ideas can be done through drawing in perspective, doing physical experiments, digital 3D-modelling, or a combination of these. Examples of three-dimensional models are shown in Figure 4. All the interviewed teachers encouraged their pupils to make some form of 3D-visualisation.

Figure 4. Three-dimensional visualisations made by pupils participating in the authors' fieldwork, using SketchUp (top), Minecraft (bottom left), and Lego (bottom right).

Alexander allowed his pupils to choose their own methods in the idea phase; some pupils worked with wooden blocks. He mentioned that he valued working with materials in the idea phase, which was also mentioned by Elise. She instructed her class to make three-dimensional sketches by taping together paper, which she found to be the most comprehensible method for form experiments. As a part of the project's introduction, Christine did an exercise in which the pupils cut out a pre-drawn shape from paper and taped it together into a three-dimensional house. Three-dimensional models, usually in cardboard but also in wood, plastic, or other materials, were a part of all the teachers' projects, although Alexander and Birgitta also included digital 3D-modelling. A physical three-dimensional model was considered useful for understanding how the planned building would turn out. Christine said that she sometimes asked pupils to imagine their cardboard model enlarged to life-size and picture how it would be to walk into it.

Digital 3D-modelling, in Ludenso and SketchUp, was used by Alexander and Birgitta. Here, the pupils used full-scale measurements instead of converting them to scale. Elise and Frida had previously used SketchUp, but the schools' implementation of iPads hindered further use. In the interview, Elise talked enthusiastically about her plans to include Ludenso in her next project. Some of Alexander's and Elise's pupils also used Minecraft in the idea phase. Being able to quickly model a structure in three dimensions, study it from different angles and easily edit it were mentioned as important attributes of digital 3D-modelling, although Alexander pointed out that its rapidity may not afford time for reflection. Alexander and Elise also highlighted the option of viewing models in augmented reality (AR), offered by Ludenso, as a new and promising feature. Through AR, pupils can view their models on site in full scale, and thus get a preview of the finished buildings.

The third way to visualise in three dimensions is by drawing in perspective, a topic discussed in all six interviews. However, its usefulness was a bit debatable – a couple of teachers described it as elusive. Alexander, who let his pupils work freely during the idea phase, said that those who had drawn their houses in perspective seemed to have less general sense of size and scale. Danielle, on the other hand, viewed perspective drawing as an important part of the preparation phase. Her pupils drew in one-point perspective before moving on to the floor plan and model at scale. Drawing in perspective was used to create a feeling for the space and as a basis for discussion on whether the room should be made smaller or larger. Birgitta and Christine expressed a desire to continue teaching perspective, even though the new curriculum does not carry this part of the subject forward. "I think it is a very important part of understanding the transition of illustrating 3D to 2D," Birgitta said.

Corresponding episodes related to the strategy

The observed pupils worked in groups on an introductory task. They were asked to design a small house by drawing a floor plan, which most groups started right away. One group did, however, fetch an iPad and make drafts in Minecraft. They said that they struggled to envision the building on a two-dimensional floor plan and that Minecraft helped spark ideas. The 3D-model especially helped them imagine the placement of windows, they noted.

A pupil who worked in SketchUp said in the interview that he struggled to visualise the finished building while drawing the initial floor plan and only drew a rectangle. Digital 3D-modelling helped him see how the building would turn out and design a more complex structure.

Introducing points of reference

This strategy entails the use of an object to orient oneself and understand or judge the measurements and scale of the model. Five of the six teachers introduced some points of reference to their pupils, the most common point of reference, was figures at scale, mentioned by all but Danielle and Frida. Christine used figures at scale most actively. She used them as the starting point, asking her pupils to design a house to fit a figure of 1 or 2 cm. The heights of the model were calculated to fit the figure, while other measurements were proportionate to the heights. Throughout Christine's projects, the figures were used frequently to gauge whether the pupils were on the right track with the scale of their models. Elise gave her pupils the task of making a metal wire model of themselves at a scale of 1:25, the same scale as the model. These figures were used while working with the models. When asked whether the scale of the model seemed correct, she would reply, "Just bring yourself out – can you get through this door?". In a similar fashion, Alexander brought a scaled figure around when his pupils were working on their physical models to check whether they had gotten the scale correct. Both Alexander and Birgitta mentioned that the software they had used, Ludenso and SketchUp, had figures in the modelling area for scaling purposes, as shown in Figure 5. They were both unsure whether their pupils had actually used them, but as Alexander said, "… he is standing there, so if it is a complete disaster, at least you understand that you've started all wrong."

Other points of reference might be asking pupils to compare the size of their models with each other's or with models from previous classes. Given that the whole class worked with the same area and scale, if one was significantly smaller or larger than the others, the scale was incorrect. Elise told her pupils that the floor of their model should be around the size of a sheet of A5 paper.

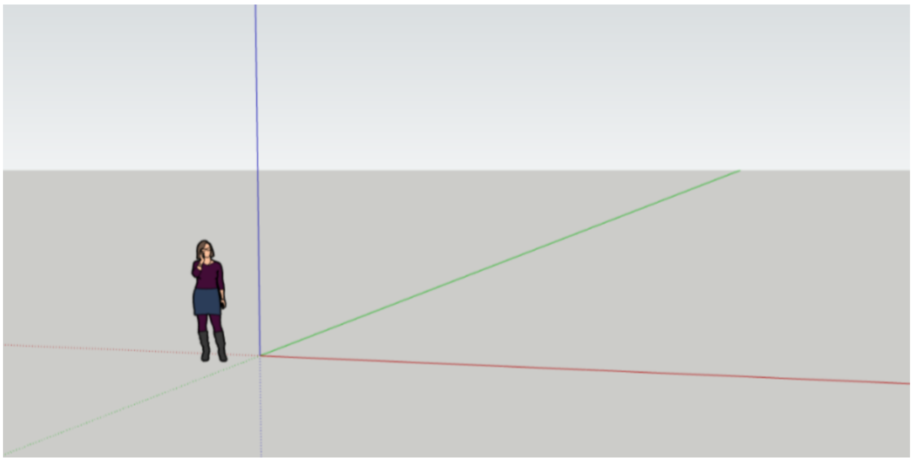

Figure 5. Screenshot of the modelling interface of SketchUp showing how the figure at scale appears at the start of the project.

Corresponding episodes related to the strategy

A couple of the interviewed pupils mentioned spontaneously that they had used "the SketchUp woman" as a point of reference. One used the software's tape measure to find her height, and then measured other items in relation to her. Another pupil said that she had moved the figure around the model to confirm that the size of the rooms was appropriate, especially in nooks and crannies.

Connecting floor plans to standards and measurements

The abstract language of symbols and numbers is connected to full-scale built environments in this strategy. It was applied in one way or another by almost all teachers, except Christine, who took a stance against the use of calculations in a practical subject such as *Art and crafts*.

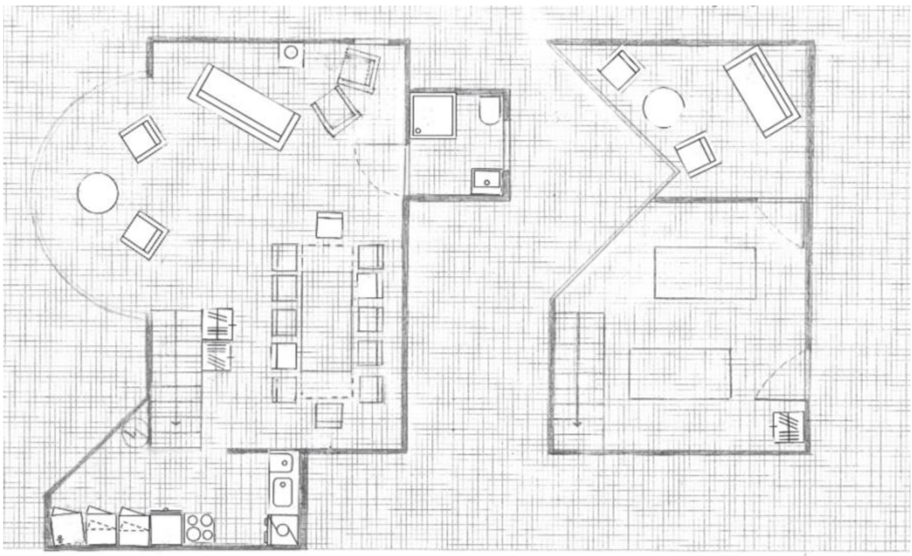

Figure 6. A detailed floor plan, drawn by a pupil participating in the authors' fieldwork, that combines cut-outs from a sheet of floor plan symbols with hand-drawn symbols.

All teachers mentioned floor plans in their interviews. Elise, who skipped traditional sketching and started instead with three-dimensional experiments, did not include floor plans in the described project, but had previously done so. For Christine, floor plans were quick sketches in the idea phase, while the other four teachers worked more thoroughly with scaled floor plans, as exemplified in Figure 6. Drawing floor plans was done in most cases as a part of the idea and planning phase, while Birgitta favoured having her pupils work on floor plans and the digital model simultaneously, so that each could inform the other. Floor plans were mentioned as a way to get an overview of the project and to use them as a blueprint for the physical model. Alexander highlighted that those pupils who drew floor plans in the idea phase tended to have better insight on the spatial properties of their buildings. Birgitta observed that adding furniture to the floor plans often helped her pupils make sense of the spatial properties, as they had a better understanding of the size of a standard bed, for example, than of square meters. A couple of teachers also mentioned that they asked the pupils to look for errors in their own or other pupils' floor plans, as a part of understanding scale.

Alexander, Birgitta, Danielle, and Frida raised their pupils' awareness of real measurements by measuring doors, windows and other items in the classroom and discussing the standard measurements of doors and floor-to-ceiling heights. These teachers expected their pupils to use realistic, scaled measurements in floor plans and physical models, and full-scale measurements in their digital 3D-models. Through experience with the measurements of specific items, it was believed that the pupils would build an understanding of how the abstract language of numbers relates to spatial properties.

While most teachers gave their pupils a set area to work with, Danielle asked them to select the area based on users' needs. This forced them to focus on functionality, determining how many square meters they actually needed rather than distributing square meters into a nice shape. Measuring furniture and equipment in their workshop, such as wood carving benches and sewing tables, prepared the pupils to decide how large an area their artists would need.

Corresponding episodes related to the strategy

The interviewed pupils were asked about their approaches to understanding how large an area they worked with. One mentioned adding furniture to the 3D-model and evaluating the area in relation to these items. "I think that's easy to see, comparing to things I know the size of," she said.

Their floor plans were drawn on grid paper with bold lines forming squares representing 1 m^2. To begin, a few pupils drew a rectangle of the entire area they were to plan and subsequently designed the shape by moving square meters from one side to the other until they were satisfied with the look. One pupil drew 100 m^2 and said that she struggled to imagine such a large area but visualising it on paper helped.

A broad range of strategies in the teachers' toolbox

When teachers assign their pupils the task of designing built environments, the pupils go through a process of visuospatial abstraction and design conceptualisations related to products in full scale (Bhatt & Schultz, 2017), as illustrated in Figure 1. The identified strategies play different roles in helping pupils make this translation between visions, visual representations, and full scale. The strategy of *facilitating embodied experience*, allows pupils to connect their visions with the full scale of their planned buildings. The experience offers a reality check for pupils of what can fit within a set area and tests how their ideas will work in practice.

Conversely, the embodied experience with full scale provides an arena for pupils to spark ideas and move from a vague notion of possibilities to feasible solutions. The strategy of *activating memories and dialogue on spatial relationships* encompasses the development of pupils' visions. When teachers initiate a dialogue, former experiences with rooms and buildings or a mental picture of new examples are used by the pupils to form and refine their visions of the built environment they are planning. This strategy can be compared to the sensemaking practice Ramey and Uttal (2017, p. 299) call "spatial analogy", in which the American pupils use their knowledge of Chicago houses to imagine a house in the Arctic. Teachers have this strategy ready at hand, but the pupils' understanding relies on their ability to form mental pictures, which in turn depends on their innate aptitudes (Buckley et al., 2018, p. 953) and prior experiences (Berkan et al., 2020). Making the connection between the pupils' ideas and the physical world occurs when teachers are *encouraging 3D-visualizations,* by drawing in perspective, making physical or digital models or a combination of these. This strategy forces abstract ideas into concrete shapes and reveals shortcomings in the pupils' visions, such as forgetting to add a staircase or the relationship between the floor plan and the site. However, the spatial properties of visual representations are elusive, since interpretation of size is dependent on the level of detail, scale, and point of view. This strategy does not require pupils to make translations to full scale – they can remain in the internal logic of the visualisation. However, Ramey and Uttal (2017, pp. 309-310) found that the use of visualisation through, for example, gestures, object manipulation, and working from sketches and diagrams was important when the learners make sense of spatial problems. The strategy of *introducing points of reference* falls within the realm of visual representations and offers tools to ensure that the scale and size of the design conceptualisations are correct. This strategy is mostly concerned with the task of creating a correct representation of the built environment and challenging the internal logic of the model. Although this strategy does not develop pupils' understanding of spatial properties, such as area and distance, it is an important part of understanding the concept of scale. Creating a correct visual representation is also crucial in the process of visuospatial abstraction, both to test one's visions and to convey to others how the full-scale built environment should turn out. The last strategy, *connecting floor plans to standards and measurements*, entails a shift between full-scale and scaled visual representations. The teachers asked their pupils to use full-scale measurements in their digital models or to calculate their measurements to the scale of their floor plans and models. This mathematical approach, with a focus on real measurements, helps remind pupils that they are planning a functional, full-scale built environment. Figure 7 illustrates how the strategies facilitate the various modes of translation.

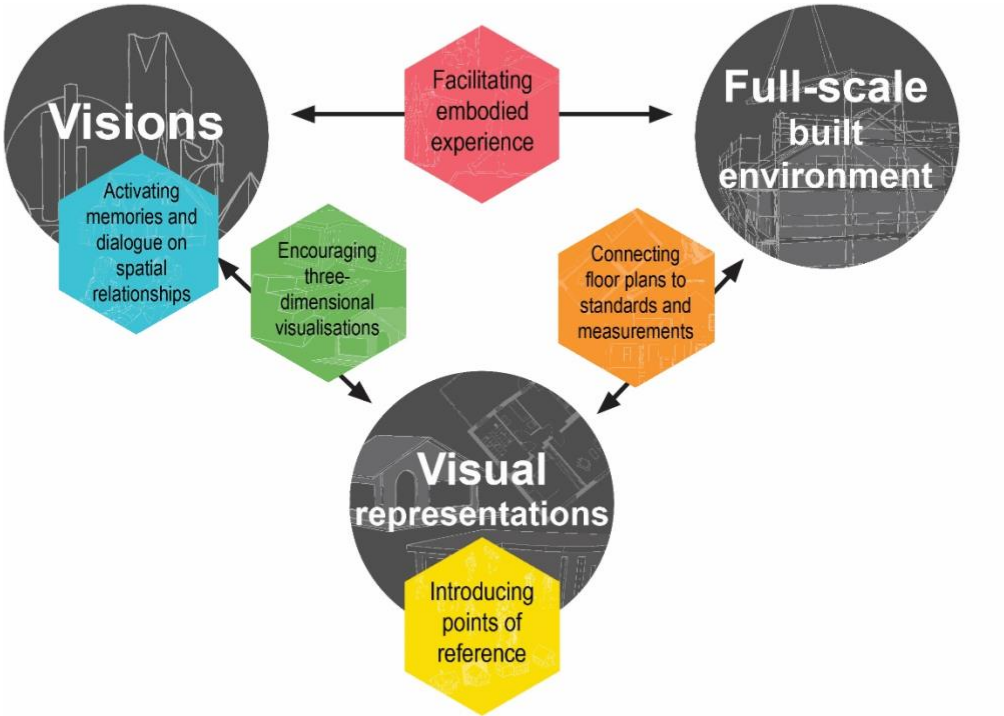

Figure 7. The strategies placed within the model of the process to visualise their roles in the process

The projects described in this article are most common in secondary school *Art and crafts*, with pupils 13–16 years old when, according to Piagetian theory, they are in the process of mastering spatial skills (Piaget & Inhelder, 1956; Sorby, 1999). Meanwhile, spatial skills are malleable and can be improved through general experience and targeted educational activities (Berkan et al., 2020; Julià & Antoli, 2016; Uttal et al., 2013). In Norway, lower secondary school is the last of the compulsory levels before choosing between programmes for general studies and programmes for vocational education and training (VET) (The Norwegian Directorate for Education and Training, 2020b). Spatial literacy is useful in both career paths as well as in everyday living. It is therefore important to facilitate the development of spatial literacy in education for the general public through, for instance, complex tasks such as designing built environments.

In working with architectural assignments and designing built environments, pupils encounter a number of challenges. Their innate aptitudes and experience with spatial tasks vary, so while some master these assignments, others find them challenging. With limited experience in handling abstract numbers relating to areas or measurements, visualising a house of 100 m^2 or a cabin of 30 m^2 might be a challenge, which in turn may lead to struggles getting started. In visual representations, pupils often encounter difficulties with scale, perhaps making the interior disproportionate to the rest of the building. Likewise, a correct representation created without reflection on functionality or the feel of the space could produce a plan that does not work as a full-scale built environment. Successful architectural processes comprise shifting between visions of what is to be built and visual representations of these, firmly related to the full-scale environment, as illustrated in Figure 1.

To accommodate pupils' different needs and challenges, teachers must have a broad range of strategies in their toolbox. In the interviews, a few of the teachers commented that they were unsure what they could contribute to this topic, as they also found it challenging. As the interviews offered an opportunity to reflect upon their own practice, it became evident that they all used a varied set of approaches. Our role as researchers has been to systematise and articulate this knowledge from the practice field. Van Dooren and colleagues (2019) and Taneri and Dogan (2021) pointed out that teachers in the architectural studio do not articulate the design process. Although the strategies presented here emerged from lower secondary school teaching, this vocabulary can also be utilised in design and architecture education to make this part of the design process explicit. In our analysis, the teachers' detailed moves were categorised and reframed into overarching strategies that elevate the individual teacher's practice into an articulated common language. This vocabulary can be developed further within the community of design researchers. Moreover, we hope to contribute to the practice field. As coined by Michael Bassey (2007, p. 141), "Educational research aims critically to inform educational judgements and decisions in order to improve educational action". We have showcased and discussed a broad range of available strategies and posited a language for discussing professional practice. We leave it to individual teachers to determine which strategies to employ depending on their singular situations. An increased awareness of possible teaching strategies may aid them both in lesson planning and in solving moment-to-moment challenges. The strategies have different properties, ranging from the abstract to the concrete, from discussions and calculations to practical work in materials, and they play different roles in the process. Figure 7 places the strategies on the translations between visions, visual representations, and full scale. Awareness of these properties and roles may aid teachers seeking to position their professional practice, decide which aspect of the project they wish to emphasize, and how to approach it in practice.

Concluding remarks

This article investigated how lower secondary school *Art and crafts* teachers enhance their pupils' spatial literacy while working on architectural assignments. Our aim was to map their current teaching practices in this topic to develop a vocabulary for the field of *Art and crafts* and Architecture education. Based on the interviews, five teaching strategies were identified and placed in a visual model to demonstrate the role they may play in aiding pupils in the process of designing built environments.

Teachers can prioritize different aspects of an architectural assignment, such as form exploration, the use of accurate measurements, or designing for functionality. Some may view this as an isolated project with its own justifications. Others wish for the learning outcome to be transferable, such as the ability to draw sketches of other products or to understand the relationship between two-dimensional representations and three-dimensional objects. Although such variation in learning objectives was found among the interviewed teachers, the five identified strategies were applied by at least five or all six of the participating teachers. This verifies that these strategies are relevant across different learning situations. In an architectural assignment, the pupils face challenges for which they have different capabilities to handle. By exploring the teachers' approaches to these challenges, we attempted to unpack some tools that can aid pupils in this endeavour. The corresponding episodes illustrate how small moves can dissolve uncertainties and difficulties, and help pupils advance through the process.

In further research, the usefulness of the identified strategies could be tested in *Art and crafts* or in architecture and design education. Relevant questions to examine are whether this articulation of the strategies and the roles they play in the design process could help teachers prepare lessons, identify students' struggles, and target their moves towards alleviating these. Alternatively, the strategies' usefulness can be evaluated from a student perspective by investigating how the students react to them and whether they use other approaches. Because we did not aim to reach data saturation, as mentioned in the methods section, a broader study including more participants could validate the results or discover additional strategies. Such a study could concentrate, as this one, on teachers with a special interest in architecture or investigate the practices of all teachers in the subject of *Art and crafts,* regardless of their background. One final suggestion for further research is an in-depth exploration of the process of visuospatial abstraction, building upon our model shown in Figure 1, to investigate, for example, the role of visual representations in the process. Although this includes visualisations in two and three dimensions, only three-dimensional visualisations came up as a strategy supporting the process. This correlates with Ramey and Uttal's (2017) study, in which only one of 31 learners was observed sketching (p. 302). As sketching and drawing are considered integral parts of *Art and crafts* (Skjelbred & Borgen, 2019), it is relevant to investigate whether, when, and how two-dimensional drawings can be used in designing built environments.

As challenging as architectural assignments may be, they are an important part of the subject of *Art and crafts*. Architecture surrounds us in everyday life, and it is impossible to be neutral about it. Most pupils will not become architects or designers, but skills developed through such assignments are useful in choosing or building private housing. Many may become involved in democratic processes regarding our built environments, either as politicians, stakeholders, or laypersons. Gaining a solid foundation for expressing visions, interpreting visual representations, and translating between visual representations and full scale through general education could contribute to facilitating real democratic processes and ensuring the quality of our built environment.

References

Bassey, M. (2007). On the kinds of research in educational settings. In M. Hammersley (Ed.), *Educational Research and Evidence-based Practice*. SAGE Publications.

Berkan, S. T., Öztaş, S. K., Kara, F. İ. & Vardar, A. E. (2020). The Role of Spatial Ability on Architecture Education. *Design and Technology Education: An International Journal*, *25*(3), 103–126. https://ojs.lboro.ac.uk/DATE/article/view/2775

Bhatt, M. & Schultz, C. (2017). People-Centered Visuospatial Cognition: Next-Generation Architectural Design Systems and Their Role in Design Conception, Computing, and Communication. In S. Ammon & R. Capdevila-Werning (Eds*.), The Active Image: Architecture and Engineering in the Age of Modeling* (Vol. 28, pp. 207–232). Springer International Publishing. https://doi.org/10.1007/978-3-319-56466-1

Brinkmann, S. & Kvale, S. (2015). *InterViews: Learning the Craft of Qualitative Research Interviewing*. SAGE Publications.

Bryman, A. (2016). *Social Research Methods* (5th ed.). Oxford University Press.

Buckley, J., Seery, N., & Canty, D. (2018). A Heuristic Framework of Spatial Ability: a Review and Synthesis of Spatial Factor Literature to Support its Translation into STEM Education. *Educational Psychology Review*, *30*(3), 947–972. https://doi.org/10.1007/s10648-018-9432-z

Buckley, J., Seery, N., Canty, D., & Gumaelius, L. (2022). The Importance of Spatial Ability Within Technology Education. In P. J. Williams & B. von Mengersen (Eds.), *Applications of Research in Technology Education: Helping Teachers Develop Research-Informed Practice* (pp. 165–182). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-7885-1_11

Cohen, L., Manion, L. & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge.

Eggebø, H. (2020). Kollektiv kvalitativ analyse [Collective qualitative analysis]. *Norsk sosiologisk tidsskrift*, *4*(2), 106–122. https://doi.org/10.18261/issn.2535-2512-2020-02-03

Emerson, R. M., Fretz, R. I. & Shaw, L. L. (2011). *Writing Ethnographic Fieldnotes* (2nd ed.). University of Chicago Press.

Goodyear, P. (2005). Educational design and networked learning: Patterns, pattern languages and design practice. *Australasian Journal of Educational Technology, 21*(1). https://doi.org/10.14742/ajet.1344

Heil, C. (2019). *The Impact of Scale on Children's Spatial Thought: A Quantitative Study for Two Settings in Geometry Education*. Springer Spektrum.

Ilić, M. & Đukić, A. (2017). Typology of spatial ability tests and its implementation in architectural study entrance exams. *Facta universitatis - series: Architecture and Civil Engineering*, *15*(1), 1–14. https://doi.org/10.2298/FUACE161113001l

Ishikawa, T. (2021). Spatial thinking, cognitive mapping, and spatial awareness. *Cognitive Processing*, *22*(1), 89–96. https://doi.org/10.1007/s10339-021-01046-1

Jerolmack, C., & Khan, S. (2014). Talk Is Cheap: Ethnography and the Attitudinal Fallacy. *Sociological Methods & Research*, *43*(2), 178-209. https://doi.org/10.1177/0049124114523396

Julià, C., & Antolí, J. Ò. (2016). Spatial ability learning through educational robotics. *International Journal of Technology and Design Education*, *26*(2), 185–203. https://doi.org/10.1007/s10798-015-9307-2

King, N. & Horrocks, C. (2010). *Interviews in Qualitative Research*. Sage.

Lane, D., Lynch, R. & McGarr, O. (2019). Problematizing spatial literacy within the school curriculum. *International Journal of Technology and Design Education*, *29*(4), 685–700. https://doi.org/10.1007/s10798-018-9467-y

Langdridge, D. (2006). *Psykologisk forskningsmetode: en innføring i kvalitative og kvantitative tilnærminger [Introduction to research methods and data analysis in psychology]*. Tapir.

Lehtinen, R., Huhtala, M. & Lindfors, E. (2021). Spatial Visualization Skills of Student Teacher Applicants: A Pilot Study in the Finnish CDT Teacher Education Admissions. *Techne serien - Forskning i slöjdpedagogik och slöjdvetenskap*, *28*(2), 278–286. https://journals.oslomet.no/index.php/techneA/article/view/4370

Liao, KH. (2017). The abilities of understanding spatial relations, spatial orientation, and spatial visualization affect 3D product design performance: using carton box design as an example. *International Journal of Technology and Design Education*, *27*(1), 131–147. https://doi.org/10.1007/s10798-015-9330-3

Lohman, D. F. (1979). *Spatial Ability: A Review and Reanalysis of the Correlational Literature*. Technical Report No. 8. Stanford, CA: College of Education, Stanford University.

Lohman, D. F. (1996). Spatial ability and g. *Human Abilities: Their Nature and Measurement*, *97*(116), 1.

Lundgaard, H. (2000, 11th of September). Skulle aldri ha tillatt dette [Should never have allowed this]. *Aftenposten*.

Macnab, W. & Johnstone, A. H. (1990). Spatial skills which contribute to competence in the biological sciences. *Journal of Biological Education*, *24*(1), 37–41. https://doi.org/10.1080/00219266.1990.9655099

Marzano, R. J. (2007). *The Art and Science of Teaching: A Comprehensive Framework for Effective Instruction.* Association for Supervision & Curriculum Development.

McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin*, *86*(5), 889–918. https://doi.org/10.1037/0033-2909.86.5.889

McLaughlan, R. & Chatterjee, I. (2020). What Works in the Architecture Studio? Five Strategies for Optimising Student Learning. *International Journal of Art & Design Education*, *39*(3), 550–564. https://doi.org/10.1111/jade.12303

Moore-Russo, D., Viglietti, J. M., Chiu, M. M., & Bateman, S. M. (2013). Teachers' spatial literacy as visualization, reasoning, and communication. *Teaching and Teacher Education*, *29*, 97-109. https://doi.org/10.1016/j.tate.2012.08.012

Neubert, P. J. (2007, 12th of September). Mur foran Operaen er et faktum [A wall in front of the Opera is a fact]. *Aftenposten*. https://www.aftenposten.co/meninger/debatt/i/g6aXJ/Mur-foran-opraen-er-et-faktum

Nielsen, C. P., Oberle, A. & Sugumaran, R. (2011). Implementing a High School Level Geospatial Technologies and Spatial Thinking Course. *Journal of Geography*, *110*(2), 60–69. https:doi.org/10.1080/00221341.2011.534171

Nielsen, L. M. (2000). *Drawing and spatial representations: reflections on purposes for art education in the compulsory school* [PhD, Oslo School of Architecture]. Adora. https://aho.brage.unit.no/aho-xmlui/handle/11250/2623403

Nielsen, L. M. (2004). Design, innovasjon og demokrati - om framveksten av forskernettverket DesignDialog [Design, innovation and democracy – the legacy of the research network DesignDialog]. In L. M. Nielsen (Ed.), *DesignDialog - designforskning i et demokratisk perspektiv [DesignDialog – design research in a democratic perspective]* (Vol. 22, pp. 3–13). Høgskolen i Oslo. https://f26b23f1-3541-4025-95b7-34caeb21f0df.fileusr.com/ugd/9bb887_82bf2aff7b9a4d08969e313130633bfc.pdf

Nielsen, L. M. & Digranes, I. (2007). User participation – real influence or hostage taking? In E. Bohemia, K. Hilton, C. McMahon, & A. Clarke (Eds.), *Shaping the future? Proceedings from the 9th Engineering & Product Design Education International Conference*, *Newcastle upon Tyne, United Kingdom, 13–14 September 2007* (pp. 305–310). Northumbria University, Headleys Ltd. https://www.designsociety.org/publication/28412/User+participation+-+real+influence+or+hostagetaking%3F

Organization for Economic Co-operation and Development (OECD). (2010). *Mathematic Teaching and Learning Strategies in PISA*. O. f. E. C.-o. a. D. (OECD).

Piaget, J. & Inhelder, B. (1956). *The Child's Conception of Space.* Routledge & Kegan Paul Ltd.

Ramey, K. E. & Uttal, D. H. (2017). Making Sense of Space: Distributed Spatial Sensemaking in a Middle School Summer Engineering Camp. *Journal of the Learning Sciences*, *26*(2), 277–319. https://doi.org/10.1080/10508406.2016.1277226

Shanthi Priya, R., Shabitha, P. & Radhakrishnan, S. (2020). Collaborative and participatory design approach in architectural design studios. *Social Sciences & Humanities Open*, *2*(1). https://doi.org/10.1016/j.ssaho.2020.100033

Skjelbred, B. H. & Borgen, J. S. (2019). Ungdomsskolelæreres oppfatninger av tegning sett i lys av den grunnleggende ferdigheten “å skrive” i kunst og håndverk. [Lower secondary school teachers’ perceptions of drawing seen in the light of the basic skill of “writing” in arts and crafts.] *Acta Didactica Norge*, *13*(1). https://doi.org/10.5617/adno.6438

Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal*, *63*(2), 21–32. http://www.edgj.org/index.php/EDGJ/article/view/126

Sutton, K., Heathcote, A. & Bore, M. (2005). Implementing a web-based measurement of 3d understanding. *Proceedings of the 17th Australia conference on Computer-Human Interaction: Citizens Online: Considerations for Today and the Future*, *Canberra, Australia.* (pp. 1–4). Computer-Human Interaction Special Interest Group (CHISIG) of Australia. https://dl.acm.org/doi/abs/10.5555/1108368.1108438

Sutton, K. & Williams, A. (2011) Spatial ability and its implication for novice architecture students. In R. Hyde, S. Hayman & D. Cabrera (Eds.), *From principles to practice in Architectural Science. 45th Annual Conference of the Australian and New Zealand Architectural Science Association.* Faculty of Architecture, Design and Planning: Sydney. https://anzasca.net/paper/spatial-ability-and-its-implication-for-novice-architecture-students/

Taneri, B. & Dogan, F. (2021). How to learn to be creative in design: Architecture students’ perceptions of design, design process, design learning, and their transformations throughout their education. *Thinking Skills and Creativity*, *39*. https://doi.org/10.1016/j.tsc.2020.100781

The Norwegian Directorate for Education and Training. (2020a). *Curriculum for Art and crafts, Competence aims after Year 10.* https://www.udir.no/lk20/khv01-02/kompetansemaal-og-vurdering/kv159?lang=eng

The Norwegian Directorate for Education and Training. (2020b). *Norwegian vocational education and training (VET)*. https://www.udir.no/in-english/norwegian-vocational-education-and-training/

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C. & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, *139*(2), 352–402. https://doi.org/10.1037/a0028446

van Dooren, E., Dorst, M. v., Asselbergs, T., Merrienboer, J. v. & Boshuizen, E. (2019). The Tacit Design Process in Architectural Design Education. *Design and Technology Education: An International Journal*, *24*(1), 79–100. https://ojs.lboro.ac.uk/DATE/article/view/2587

Yorgancioğlu, D. & Tunalı, S. (2020). Changing pedagogic identities of tutors and students in the design studio: Case study of desk and peer critiques. *Art, Design & Communication in Higher Education*, *19*(1), 19–32. https://doi.org/10.1386/adch_00011_1

Appendix A:

Interview guide for the semi-structured interviews with teachers

1. What is your education?
2. How many years of teaching experience do you have?
3. Is your school a lower secondary school or Year 1-10 school? At which level do you teach Art and crafts?

4. You have been chosen to participate in this interview because we have heard about an architectural assignment where you …… Can you tell me more about how you worked on this project?
    - Which finished product did the pupils work towards?
    - What was the duration of the project?
    - Which part does the pupils usually start with?
    - Did the pupils make a floor plan or a model at scale?
    - Did the pupils work digitally, analogue or a combination of the two?
    - Why have you been teaching in this way?
    - In your experience, how have the pupils' responded to this way of teaching? Have you seen any changes to their products or their learning outcomes?
5. What is the most important learning outcome the pupils can have, in your opinion?
6. Is there something you have noticed that pupils often struggle with or find difficult?
    - Which actions or moves have you made to make this easier for them? And which effect have this had on the pupils?
7. In your experience, how does pupils master the task of imagining the finished product? In example, how large will it be, how much can they fit into a certain area, what the spatial properties and feel of the room or area would be?
8. Which actions and moves do you make to help the pupils to get an understanding of the size of a room, e.g. on a floor plan, how tall a building is, e.g. on a scaled model, how big an area a square meter really has?
9. How do you prioritize teaching architecture in the subject Art and crafts?
10. Why do you regard this as an important/not important topic for the pupils to learn about?
11. Is there something else you wish to discuss in relation to teaching the topic of architecture?

Affordances of models and modelling: a study of four technology design projects in the Swedish secondary school

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Abstract

This study aims to investigate affordances of models and modelling in design projects in technology education. To learn more about affordances when working with models and modelling, four Swedish technology teachers were interviewed using a narrative approach. Despite a small number of informants data were rich, containing detailed descriptions of sequences where students used models and modelling in ways not planned by the teachers. By using a qualitative, generic inductive approach, the narrative interviews revealed seven different affordances of models and modelling in the projects: *Seeing different solutions; Finding possibilities and limitations in solutions; Representing an idea, structure or function; Communicating solutions with drawings; Making problems and solutions visible; Trial and error and learning from mistakes* and finally *Taking inspirations from each other's solutions.* Some conclusions and implications of the study are that when the students can see and use a wide variety of materials when modelling, they are more creative in finding solutions to design problems. The use of conceptual design in schools, leading to students performing trial and error using models to solve problems, might also be connected to the importance of a variety of materials. In the study, teachers describe how their students used models, trying different solutions, representing ideas, and trying, failing and trying again. All these modelling activities are important parts of a design process and might prove that the doing itself is a process of reflection.

Keywords

Models, Modelling, Design project, Affordances, Technology Education

Introduction

Learning to solve technological problems, as well as learning how to use a design process to solve these problems, are central to many countries' school technology curricula. Models and modelling play an important role in design processes by enabling testing of the qualities and capabilities of a solution and developing it further. However, we need more knowledge about the use of models and modelling in design projects in technology education in compulsory schooling.

In order to learn more about models and modelling, this study examines technology teachers' narratives about successful design projects performed with their students. These narratives could be an important contribution to the knowledge about *affordances* of models and modelling in a design process. Affordances can be described as action possibilities (Norman, 1988). Thus, what possibilities do models and modelling offer to students in the development of technological knowledge in a design process? In a research project of which this study is the third, we aim to deepen and expand knowledge about the use of models and modelling in the school context.

In prior studies, we examined technology teachers' perceptions of model functions in technology education (Citrohn & Svensson 2022) and the use of models and modelling in classroom design projects (Citrohn et al., 2022). While the first study was about *teachers' perceptions*, the second study examined *what actually happened and what was discussed* about models in technology classrooms.

There is also prior research concerning models and modelling in for example, the nature and properties of models were investigated by Nia and de Vries (2017), leading to a framework for analysing models: 'the dual nature of models', consisting of an intrinsic and an intentional nature. An investigation of models and modelling in industrial design led to a classification of physical models like Soft model, Hard model and Presentation model (Isa & Liem, 2014).

A study of models and modelling in STEM (Science, Technology, Engineering, Mathematics) education led to the implication that models and modelling could be used as a bridge between different subjects in STEM (Hallström & Schönborn, 2019). The use of digital models and modelling in technology education (Brink et al., 2021) indicates that technology teachers experience digital models as an amalgam of multiple ideas.

However, none of the above-mentioned studies focus on affordances of models and modelling in school design projects. To our knowledge, a discussion about models and modelling and the affordances of students' use of them in design projects it is still missing in previous research. The present study aims to contribute to the knowledge about affordances that arise when students use models and modelling in unexpected ways that are nonetheless relevant to teachers' plans for the design project. The study uses a qualitative, generic inductive approach, where the data is based on episodic narrative interviews (Mueller, 2019) with Swedish technology teachers in grades 7-9. To meet this aim, the study will answer the following research question:

> Which affordances of models and modelling can students discern, according to teachers' narratives about successful design projects?

Design process, models and modelling

Almost everything surrounding us, except for nature itself, is, in one way or another, designed by humans (Wikberg-Nilsson et al., 2021). The purpose of performing a design process is often to find a solution to a technical problem, perform a development or improvement of an existing product, or to find a completely new product (Wikberg et.al. 2021). Design is described as a purposeful creative act, and it is the basis for creation in a technologically constructed environment (Papanak, 2000). Thus, a design process is not easily defined because of the many uses of the concept in the work of different professional groups. The design processes sometimes differ, but the aim of all process is to produce a design as described by Anthony et al. (2012):

> *Design is a many-splendored activity: architects, engineers, graphic designers, industrial designers, interior designers, landscape designers, fashion designers, computer hardware and software designers (and many others) are all designers, and they all produce a design which is the outcome of a design process (designing). (Anthony et al., 2012, p.93)*

Engineering and technology are professional fields that take design as an important and distinguished activity (Dym, 1994; Li et al., 2019). A design process includes different steps, described in different ways in different contexts, but always starting with a *Problem definition*. This step often includes addressing well-defined to ill-defined questions, with the purpose of getting a view of the problem by identifying the constraints governing it. There are also steps that include *Suggesting solutions* using models, sketches, and drawings to test the qualities and possibilities of a solution and to develop it further. At the end of Dym's design process, there is an *Evaluation and decision-making step* where different solutions are assessed objectively based on their advantages and disadvantages (see e.g., Dym, 1994).

The use of models in a design process in engineering and technology is central to making ideas more accessible to oneself and others, as well as enabling testing and changing solutions before deciding on the final solution (Norström, 2013; de Vries, 2013; Welch, 1998). Physical models are also being used to visualize an idea to a potential customer, or to show a specific function (de Vries, 2018). Furthermore, a conceptual model could be used for planning the whole design process by representing the different phases in the process (de Vries, 2018). In this study, the focus is on the use of models and modelling in a design process, as presented and used in Swedish compulsory technology education.

In general, there are no general differences between modelling in technology and modelling in engineering (Williams, 2011). However, some small but important differences have been shown by research: design in technology is not qualified as science and has no rigorous rules for progression (Lewis, 2005). Furthermore, there is an absence of mathematical analysis in technology (Gettie & Wicklein, 2007). This leads to a division of design into *conceptual design* and *analytical design*, where the former is common in the school context and the latter is more common in the engineering context (Williams, 2011). Conceptual design is less predictive, often leading to a process of finding out what works as a solution to the problem. The solution is evaluated based on its ability to solve the stated problem. In technology education, like in the school context, there are limited possibilities for predicting what works – thus, it is the process of experimenting and modelling that leads to a solution (Williams, 2011). Even expert technologists need to have hands-on experience with their designed products in order to choose the right materials (Potter & France 2018). In analytical design, like in engineering, experimentation and modelling are done to verify a solution before its development (Willams, 2011).

Engineering design is described by the Swedish National Agency for Education (Skolverket, 2021) as consisting of two main parts: *The designing part*, where the idea of the product is launched using sketches, drawings, and a model of the intended product; and *The production part*, where detailed drawings and prototypes, as well as the production of the final product, are carried out (Figure 1). Only the design part, consisting of six steps (*Identification of needs, Investigation, Proposing solutions, Constructing, Testing* and *Documenting solutions*), is performed in Swedish schools (Skolverket, 2021). Regarding the engineering design process (EDP), Dym (1994) proposes five overarching steps, with several small steps within each of them (Figure 1). Important to bear in mind is that there are many ways of describing the EDP, and that the kind of design process being used in school is a subset of the EDP. In the designing part, which is about identifying and researching the problem and developing possible solutions, the materials used might be important. Telier et al. (2011) refer to the term *Materiality* as a technical property of materials from which a designed artefact is made, referring to Mori (2002), who argues that materials are a precondition for promoting ideas and creativity. Telier et al. (2011) argue that in a classroom or a studio for designing buildings, where materials are often random collections of leftovers and samples, finding material for the model may influence the choice of materials for the building. The availability of different materials is necessary for exploring different aspects like the technical, the aesthetical and the conceptual.

The EDP always is connected to a real problem or need; however, the school design process might be connected to an imagined problem or need. When planning a design process in a school context, the teacher might strengthen the connections to the real world, and the complexity, by specifying users and functions (Citrohn et al., 2022) The end of the school design process is of course different from the complete EDP (Figure 1). The engineering design process also includes the optimisation and evaluation of a prototype, as well as communicating the final result in the form of construction drawings and production documents (Dym, 1994). The school design process' possible outcome is often a physical model that might display the student's intentions for the final product (Citrohn et al., 2022).

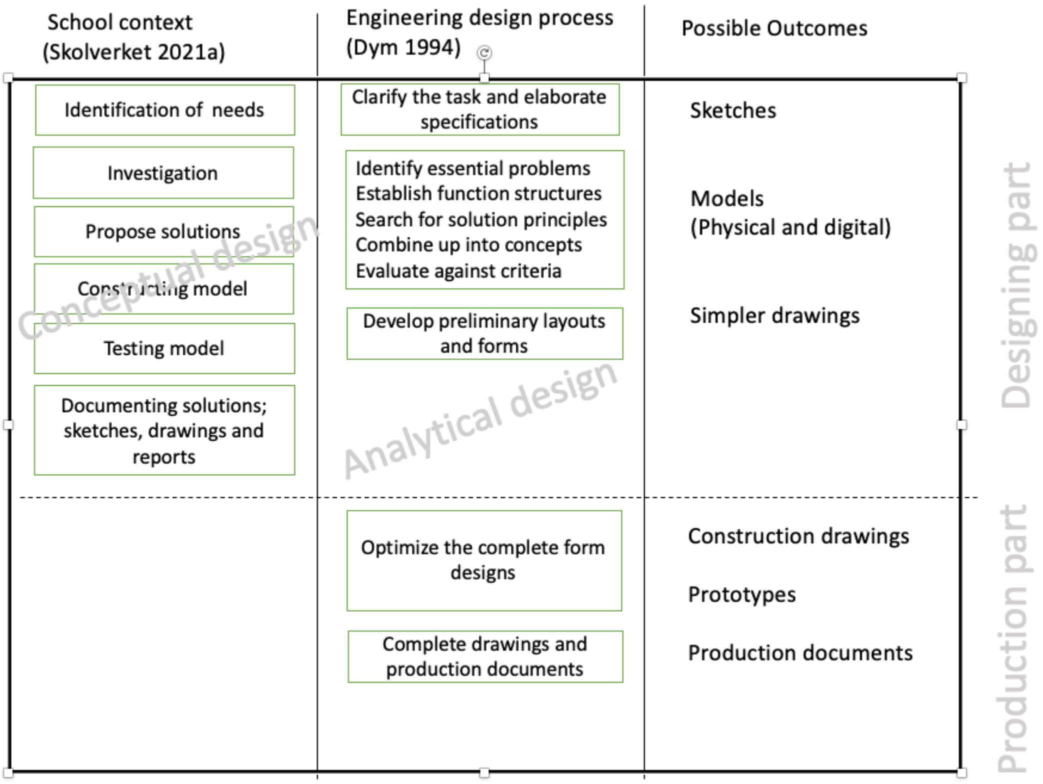

Figure 1: A technology design process and EDP with possible outcomes.

Affordances in a design process

Affordances is about the relation between objects, actors and their connections. James Gibson (1979) defined affordances as offers, or information, that exist in the environment around the actor. The actor has *action possibilities in a certain environment* that are measurable and dependent on the capability of the actor (Teiler, 2011).

In this article we use a definition originating from Norman (1988) who refined Gibson's concept and showed how it could be used in design. He defined affordance as "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (Norman, 1988, p. 9). Later, Norman defined action possibilities, affordances, as an *implicit communication* between the designer and the user of a product. He also argues that one important way that people function is the ability to discover and make use of affordances (Norman, 2009).

In this study we use the concept of affordance when examining students' and teachers' use of models and modelling in a design project. Sometimes in design projects, affordances of models and modelling for students and teachers, respectively do not correspond to each other. That is, *students and teachers see different action possibilities in models and modelling*. These instances, in teachers' narratives of a design project, are examined in this study.

Method

To answer the research question, four Swedish, fully licensed, experienced technology teachers have been interviewed. The teachers were selected through a purposive sample (Robson & McCartan, 2016). They were working in different schools, grades 7-9 (students aged 13-15) and were selected for the interviews because they had recently taught design projects involving student modelling. Their projects represent a variety of projects being performed in Swedish schools but also a waste majority of the aims in the knowledge area of *Working methods for the development of technical solutions* the Swedish curricula for technology (Skolverket, 2022). Furthermore, the four teachers performed their projects within five classes, containing in total about 120 students.

Data was collected using Episodic Narrative Interviews (Mueller, 2019). In such interviews, the focus is on a phenomenon, for example an event. In this case a design project is the phenomenon that the teachers were asked to describe in rich detail. They were encouraged to talk about the work with models and modelling in a design project recently performed in their classes. As preparation for the interview, each teacher was asked to answer written questions about a design project that they had performed in their teaching and that they found to be successful. The teacher was invited to describe the aim of the project and to share with the researcher any other information given to the students. The aim of asking the teachers to write about the project was to prepare them for the interviews through reflecting on their projects. The written answers also helped the researcher to prepare for the interview. Moreover, to give the teacher time to reflect during the interview, and thus as an interviewer leave some paus for thinking is important to ensure high quality data (Mueller, 2019).

The interviews were performed and recorded at the end of 2021 via Zoom, an internet-based video conference system.

Ethical considerations of the study

This study follows the ethical guidelines of the Swedish Research Council (Vetenskapsrådet, 2017). The teachers were given information about the project and written consent was given before the interviews. The teachers could at any point withdraw from the study. Since the data consist of interviews with the teachers, consent from the students or their guardians was considered unnecessary. The study was registered at Linköping University's personal data processing unit. The teachers have been pseudonymized to ensure their and their students' anonymity.

In the following section, a summary of each of the four projects is presented. In Sweden, the teacher is free to choose the specific content of projects, as long as the core content and knowledge requirements in the curricula are fulfilled. The four different teachers all work with design projects in technology education, but the content, aims and presumptions differ – hence the four projects represent a variation of design projects in Swedish technology education. All of them are related to the knowledge area of *Working methods for the development of technical solutions* the Swedish curricula for technology (Skolverket 2022). They should be interpreted as four different examples that represent a variation in Swedish technology classrooms.

The bridge project

In the bridge project, the students use their theoretical knowledge when designing strong and stable bridges. The students had theoretical lessons about different materials and how to influence the tensile and compressive strengths but had no prior experience of working with the school design process. The students were to construct a miniature bridge (Figure 2) in the form of a suspension bridge between two desks, in which the lightest bridge which could support a specified weight would be the winner of the project. The students were in grade 7 and worked in teams of 2-3. First, they made a sketch of their intended bridge. Second, after approval from the teacher, they were to build a 3D-model of the bridge. They had access to the internet to search for real bridge constructions (Figure 3). The building material was specified by the teacher and consisted of glue, a glue gun, lolly sticks and matchsticks (Figure 2). The students were able to test their bridges during the modelling process. Finally, all bridges were tested with a specified weight, and the teacher led an evaluation of the construction of the bridges. Pros and cons of the different bridges were discussed, and the students evaluated their bridges individually, in comparison to other students' bridges. The evaluations were noted in logbooks, which had also been used during the construction process to document the design process.

Figure 2: Students building a bridge (Photo from the teacher of the project)

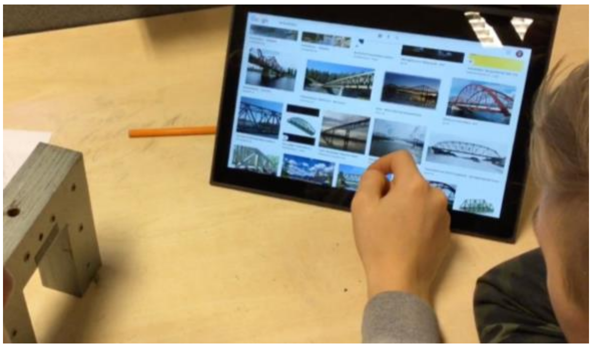

Figure 3: Students examining real bridges (Photo from the teacher of the project)

The optical telegraph project

As a part of a larger project about the history and future of communication, grade 8 students constructed a full-scale optical telegraph from which they could send messages to other students far away. The students had no experience of working with the school design process before, and the only specification given by the teacher was that the optical telegraph was to be built on a large piece of cardboard and that it was to contain nine hatches (Figure 5) that should be operated by the students in order to send messages. The students had free access to materials found in the technology classroom like cardboards, lolly sticks, matchsticks, dowels, rubber bands, cotton string, small wooden boards, tape, glue, and glue guns. Moreover, the students had access to materials from the craft shop. The students worked in teams of 2-3 and were supposed to document their process in logbooks. During the project, the students themselves, without any influence from the teacher or knowledge of the design process, decided to build small-scale models of their telegraphs to try out functions (Figure 4). They had access to different materials and the project ended in testing of the full-scale telegraphs with groups of students standing far away from each other sending messages between them with their telegraphs.

Figure 4. A scale model of a telegraph. (Photo from the teacher of the project)

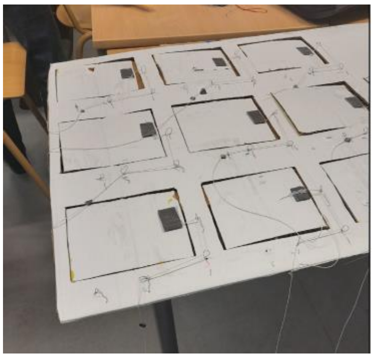

Figure 5: A full-scale optical telegraph (Photo from the teacher of the project)

The design a chair project

In the Chair project, grade 7 students (13 years old) designed a scale model of a chair that was to be used in a school-environment. In reality, the school was about to change classroom furniture, so the project was somewhat authentic. The students, which had no prior experience of design processes, designed the chair from a list of specified criteria such as sustainability, environmental friendliness, ergonomics, and economy. After being presented to the project they started drawing a sketch of the chair mowing on to designing a 3D drawing in Thinkercad. Finally, the students constructed a 3D scale model of the chair (Figure 6). During the constructing phase they had free access to materials in the technology classroom, for example, cardboard, lolly sticks, matchsticks, wood dowels, paper dowels, rubber bands, pulp balls, cotton string, small wooden boards, tape, fabric, glue, and glue guns. Parallel to designing the students were to describe the progress of their design process using text and figures in a logbook. They were instructed to describe their choice of materials and design of their intended final product and the consequences for humans and the environment. The project resulted in many scale models and one goal was to create a catalogue of all the models, with the intention of making it even more authentic for the students.

Figure 6: Scale models of chairs (Photo from the teacher of the project)

The greenhouse project

In the greenhouse project, grade 7 students constructed a scale model of a greenhouse (Figure 7), temperature regulated by a micro:bit controlling a servo opening a window on the roof or the door. The students had not worked with the school design process before, but they had some experience from programming micro:bits. The greenhouses were made using wooden sticks and rolled paper, and the windows were made from plastic film. Materials used in the project included cardboard, lolly sticks, matchsticks, wood dowels, paper dowels, rubber bands, cotton string, straws, and pulleys. The micro:bit was programmed by the students to start the servo to open a window at a specific temperature. Before the students started to build, they made a sketch of their intentions. Then, they constructed their greenhouse and, after finalising them, they made an exact drawing with the measurements. The students also used a logbook to document their design process.

Figure 7: A scale model of a Greenhouse (Perez & Nord, 2021) used with permission from Teknikundervisning i skolan

Analysis

The teachers' written descriptions of their design projects were used to get the broader context of the projects, preparing both the researchers and the teachers for the interview. The descriptions were also used, together with pictures from the teachers, to summarize the projects in the section above. However, the data material used for the analysis in this study consists of the transcriptions of the interviews with the four teachers.

The analysis could be described as an inductive qualitative content analysis (Graneheim & Lundman, 2004). To become familiar with the data, the transcribed interviews were read through several times. The episodic narrative interviews contained rich descriptions of the teachers' intentions and how they were carried out in teaching. One of the strengths of this method is that the interviewees are able to elaborate on the phenomenon. Moreover, the request for details tend to yield rich narratives (Mueller, 2019). The teachers also described the students' activities and how they responded during the project.

In the first stage of the analysis, the first and second author searched the data for sequences where the teacher had an intention with the teaching design, while the students saw other possibilities. This could be episodes where the students came up with new ideas that the teacher had not thought of, or when the students tried too complicated solutions. Hence, these instances are examples of where the teachers and students saw different affordances of models and modelling. After the initial selection, the other two authors were consulted, which resulted in a few changes. In total, 20 excerpts were selected for coding. The coding was performed in two stages – an initial stage with the two first authors, and then a second stage where the codes were confirmed by the other two authors.

The codes were clustered in three different themes, three different contexts, in which different affordances of models and modelling were detected. The themes were; *1. Materials being used in project, 2. Drawings as models*, and finally *3. Process of conceptual design.* These three themes constitute the sections in the results. Of the initial 20 excerpts, the 11 most representative were selected for illustrating the different affordances in the results.

Results

The affordances from the different projects were compiled into the results of the study. When examining the excerpts from the interviews, we were able to identify model and modelling affordances in all four design projects. The excerpts could be connected to three different themes: *1. Materials being used in project, 2. Drawings as models and 3. Processes of conceptual design*. In the three themes seven different affordances of models and modelling were found; *Seeing different solutions, Finding possibilities and limitations in solutions, Representing an idea, structure or a function, Communicating solutions with drawings, Making problems and solutions visible, Trial and error and learning from mistakes and finally Taking inspirations from each other's solutions.* An overview of themes and affordances is displayed in figure 8.

It is important to be aware that the data is based on the teachers' narratives of events in the classrooms.

Theme 1. Materials being used in project

The first theme is related to materials being used in the projects. By using a greater variety of materials when modelling, the students were able to see different solutions when constructing the model. Hence, models and modelling afford *seeing different solutions* by enhancing the cognitive process of designing solutions, when seeing and using a variety of materials. In the optical telegraph project, the students came up with different solutions when working in the technology classroom. However, when they were allowed to visit the craft shop and meet a greater variety of materials which influenced their cognitive models. A cognitive model is an internal representation used to generate external representations, for example a physical model (Buckley 2000). A person's cognitive models can be influenced by models, phenomena and information. When the students were influenced by the materials in the craft shop, they were able to come up with even more solutions and ideas;

> *We have this in the craft shop, we can get it there (students). Students see other solutions than I do, because I only think about the material, I have in front of me. (Excerpt #1, Optical telegraph).*

Thus, the materials offer more possible solutions for the students' modelling. Models and modelling with a variety of materials afford students creativity when finding different solutions. Models and modelling with materials also afford students *finding possibilities and limitations in* *solutions.* For example, optimising the use of materials when constructing. In the bridge project, the students discovered that the actual amount of material could be reduced compared to their original hypothesis. When constructing their cognitive model and their sketches, they believed that they needed more material to make a strong and stable construction. However, when they started building the model, they noticed that material use could be minimised;

> *When they saw that it seemed to be very stable, they realised that they could actually remove some material and didn't have to use it. (Excerpt #2, Bridge)*

The modelling activity affords finding possibilities in the solution. On the other hand, in the greenhouse project, a student had the idea of constructing a sliding hatch, but in this project the materials limited what was possible.

> *There were students who aimed for quite complex solutions and maybe had to back it up later. One student made a sliding hatch, he had some kind of rails, he needed better ropes… A cool technical solution, but it was never finished. (Excerpt #3, Greenhouse)*

The materials afford both what is possible and not possible in construction. The models with the material being used serve as an indicator of possible or impossible solutions. Furthermore, when *representing an idea, structure or a function,* models offer affordances in relation to materials being used. Since everyday materials often are used in schools when representing quite advanced cognitive models, the affordances of models and modelling are helping students represent advanced models with everyday materials. In the chair project, a student wanted to build a chair with wheels. The teacher suggested that he use pulp balls to represent the wheels.

> *We do not have a great variety of materials. A student planned to have wheels on a chair. So, what could we use as wheels? Yes, pulp balls! This looks a bit like wheels, so we used them. You have to invent a lot during the process, I said to the student. (Excerpt #4, Chair).*

In a desk chair with wheels, the wheels are constructed as mechanical moving cylinders with function and structure considerably unlike a pulp ball. However, the teacher suggests the student uses the ball, hence in this model the ball represents an *idea* rather than a function or a structure. The material affords *representing an idea* in the model. In the greenhouse project, the students started to cover the frame of the greenhouse model in plastic film, to represent the structure of a greenhouse. However, the teacher wanted them to focus on representing the function of opening and closing the windows or doors.

> *There were many students who started out with the plastic film, but it is difficult to work with mechanisms if you have covered them in plastic. So, I had to tell them to wait with the plastic film until the end. (Excerpt #5, Greenhouse)*

The students wanted to *represent a structure*, while the teacher wanted to *represent a function*. In this kind of tension, it becomes obvious that the teacher and students see different affordances in the modelling process. Hence, *representing an idea or a function* is an affordance of models and modelling.

Theme 2. Drawings as models

Another cluster of models and modelling affordances is related to drawings being used in the projects. A drawing can be considered a model (Gilbert, 2004) and one example of an affordance is *communicating solutions with drawings.* In the greenhouse project, the students worked in a different sequence compared to the other projects. The students started by sketching the greenhouse quickly – then they constructed the model and tried different solutions. When they were satisfied with their model, they made a drawing of it.

> *They make the drawing based on their model. It is not a drawing of a real greenhouse, but rather a drawing of their model. They do not change in the sketch when they change the model, I think that kills their creativity. They finish the model, and then they make a drawing of the model. (Excerpt #6, Greenhouse).*

This is interesting because a common way to perform modelling in Swedish schools is to evolve the model and the sketch at the same time or make a drawing of the intended product before building the physical model. However, in the greenhouse project, the drawing is a representation of the physical model, not the intended product. Models in forms of drawings have the affordance of *communicating solutions*.

Another affordance of models in the form of drawings is *making problems in solutions visible.* In the chair project, a student made a mistake when constructing the physical model seat. The seat was highly disproportionate in relation to the legs of the chair. The teacher made a drawing in which the mismatch in proportions was displayed in an obvious way.

> *It should look like you can enlarge, everything should be proportional in the model. Someone made a little mistake, and then I drew the model so that the mistake became clear. (Excerpt #7, Chair)*

Models in the form of drawings have the affordance of making a problem, for example the proportions, visible.

Theme 3. Processes of conceptual design

The third theme is connected to *Processes of design.* In our study the process involves the students work from a cognitive model to a solution of the problem in form of a physical model, thus a conceptual design (Williams, 2011). In the bridge project, the students had initial ideas, cognitive models and sketches of how to construct the bridge, but when testing their ideas in a physical bridge and failing, they realised that they had to solve the problem in another way. They did *trial and error and learned from mistakes* when solving the problem.

> *Some students had an idea in the beginning, but in practice some of them reformulated it quite a lot when they realised that the bridge didn't hold anything. They make a bigger journey and actually learned the most. Those who have done the most wrong are the ones who have learned the most. (Excerpt #8, Bridge)*

The teacher in the bridge project emphasised that the students who most used trial and error were those that learned most during the project. When students tried, evaluated and reconstructed their conceptual models, they developed their perceptions of different solutions and of which solution best fits the purpose in different situations. Thus, the affordance of using models is *trying, failing and retrying in order to learn* and to construct and evolve the cognitive models during the process. On the other hand, some students learned at the end of the process. Some students in the bridge project did not listen at all to the teacher's advice on construction – they constructed the bridge following their own cognitive models. However, in the end, when evaluating the bridge, reality caught up, and their cognitive models proved wrong.

> *What's interesting is that some students really think completely freely. They have not listened at all or think that they can do it in a cleverer way. They find another way, but still the analysis phase catches up with them in the end. I really like students who think outside the box in their own way. I think it is important that we affirm this in school and that it is also perfectly okay that it will be wrong. Why was it wrong? The analysis is important. (Excerpt #9, Bridge)*

Thus, one affordance in processes of modelling is learning from mistakes when analysing the result of the process. Another affordance in the process of modelling is *taking inspiration from each other's solutions.* In both the greenhouse project and the bridge project, the students imitated each other's solutions. If a student or a group of students came up with a clever solution, the solution spread through the class and several students started using it. Sometimes, even the teachers spread student solutions between classes.

> *If a student comes up with a smart solution, then other students see it and they start imitating each other. Maybe I show that solution to the next group and then there are many who pick it up. Yes, and I'm trying to urge you to do that. I call it industrial espionage. (Excerpt #10, Greenhouse)*

The affordances of models and modelling in processes is spreading clever solutions. The spreading of ideas might also involve the process itself. In the optical telegraph project, student groups started to build small-scale models in order to solve one function at a time on a small scale (figure 4) before constructing the full-scale telegraph, which contained a lot of functions.

> *Someone came up with an idea of building a small scale-model before building the actual telegraph, which spread through the class. Some students worked with just one box in the small-scale model, and tried to make it work, and then apply it into the large model later. (Excerpt #11, Optical telegraph)*

For the students, taking inspiration from other´s solutions is important for the problem-solving process. The seven different affordances of models and modelling divided into three different themes is displayed in figure 8. Next, we are going to discuss our results and draw some conclusions from them

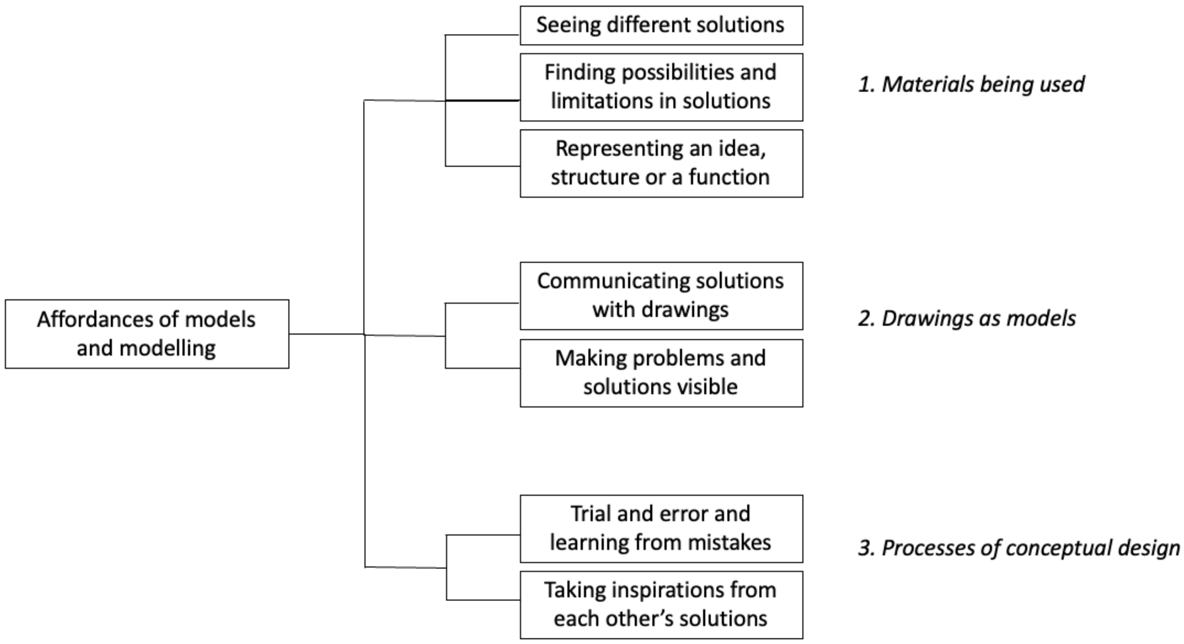

Figure 8: An overview of affordances and themes in this study.

Discussion

The present study answers the research question: Which affordances of models and modelling can students discern, according to teachers' narratives about successful design projects? In this section we discuss and conclude our results.

When using physical models, students in our study were able to *see different solutions* but also *find possibilities and limitations in solutions.* When the students were able to see and use a wide variety of materials, they were more creative when finding a solution. This connects to Telier et al., (2011) and the term of *materiality*, a sort of precondition for promoting ideas and creativity. Moreover, Schön (1983) states that designing could be defined as "a reflective conversation with the materials" (p. 172). Our study indicates that students were able to see different solutions to their problems when they were handling different types of materials. For example, in the Bridge project, when the students only had access to their pre-knowledge, they were restricted to a few possible solutions. However, students that were exposed to a variety of materials, like in the optical telegraph project, found new solutions that they had not come up with on their own. This means that a greater repertoire of materials could give the students new ideas that are not limited to their own pre-knowledge. This implicates that depending on what the teacher wants the students to learn, they could offer different varieties of materials.

Another affordance of the materials is to represent an idea, a structure, or a function. Materials used in technology classrooms are often everyday materials, and the students must display their intentions of the final product with simple materials. For example, the students in the chair project used pulp balls to represent the wheels of a chair (Excerpt #4). The pulp ball represents the idea of a wheel. This might be connected to the complexity of the project, thus if the student is supposed to show their intentions of the final product in their model (Citrohn et al., 2022).

An implication for technology education and technology teachers is the significance of providing students with a rich variety of materials, as this seems to be beneficial for students' creativity (Excerpt #1). Furthermore, earlier research suggests that another important factor for students' creativity is their prior experiences and knowledge (e.g. Esjeholm & Bungum, 2018). Overall, the materials being displayed are important, and we suggest that this relationship between students encountering a rich display of materials and their creativity should be further investigated in more depth and detail.

When examining Figure 1, which includes two interpretations of the design process, the second step of the EDP corresponds to three steps in the school design process: purpose solutions, constructing model and testing model. These 3 steps correspond to the process of modelling and all seven affordances identified in this study. Thus, the usage of models and modelling affords the modelling steps in the design process.

Since our study is connected to the school design process, the process used in our study is about conceptual design (Williams, 2011). Evidence for this is the affordance of *trial and error and learning from mistakes.* The students have to use trial and error to find the right solution, since they are not able to use the analytical design used in the EDP. The school use of conceptual design might also be connected to the importance of a variety of materials in performing trial and error. We suggest further investigations in order to widen knowledge about the variety of materials and conceptual design used in schools.

In summary, this study shows that models and modelling afford more than just unreflective doing. Swedish technology education has been criticised for putting too much emphasis on building and less on reflection (Skolinspektionen, 2014). However, our study indicates that the doing is itself a reflection process. This could be compared with Schön's concept of reflection-in-action (Schön, 1983). Haupt (2018) argues that the systematic approach of a design process requires the students to fill in the gaps and solve the upcoming problems. Our results show that the teachers talk about students trying different solutions, representing ideas, trying, failing, and trying again. All these activities are important parts of the design process that also entails the students to engage in a reflective process (see Schön, 1983). The design process and creative thinking are, and ought to be, chaotic processes. From an outsider's perspective, this might look unreflective and unsystematic. However, the teachers that participated in this study talk about their design projects as successful, and the students explore the materials, the possible solutions and thereby also learn about the design process in an authentic way. Since all four teachers in this study are trained, licensed, and experienced technology teachers, their professional view of what the students do in the classroom have implications for our interpretation of what the students are "doing" when designing.

Furthermore, the affordance *of taking inspiration from others* is an important part of the design process, both in school and real-life contexts. The results indicate that the teachers observe that the students take inspiration from the students that is viewed as being the "clever ones" or the "best ones" on a specific topic. But whether this behaviour really is wise could be questioned. In a similar vein, it is common that students take inspiration from pictures and drawings found on the internet. We suggest that it would be important in future studies to study the relation between these observed, common behaviours and students' creativity when working with a design. Does seeing how others have solved similar design problems open for students to see new, creative, solutions – or do these constrain and limit their vision?

Limitations of the study

This study is based on a small number of interviews that should be seen as four projects representatives of design projects in technology classrooms in Sweden. With this episodic narrative interview technique, the teachers can provide their view on what happened in the classroom. However, we should be aware that the data mirror the teachers' subjective descriptions of the teaching, and that should not be equated with what actually happened in the classroom. As Mueller (2019) states: "a narrative is an internal, subjective account of a socially constructed experience" (p. 8). Even so, we would argue that the professional lens of teachers should be legitimised as accurate for classroom observation and interpretation.

Implications of the study

This study implicates that the materials that students are allowed to use in a design process, potentially will affect their creativity and thereby what solutions they are able to come up with. If teachers want their students to come up with many different solutions, they should offer a great variety of materials. Moreover, our results indicate that the trial-and-error process that the students engage in during design projects, could be interpreted as reflection-in-action, and not just an unreflective act of doing. However, we suggest that the students' more systematic trying could be a sign of more reflected action. This need to be further investigated in forthcoming research.

References

Anthony, W., Cowdroy, R. & Wallis, L. (2012). Design. In: Williams, P.J. (eds) *Technology Education for Teachers. International Technology Education Studies*. Sense Publishers, Rotterdam. https://doi.org/10.1007/978-94-6209-161-0_5

Brink, H., Kilbrink, N. & Gericke, N. (2021). Teaching digital models: secondary technology teachers' experiences. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-021-09659-5

Buckley, B. C. (2000) Interactive multimedia and model-based learning in biology, International Journal of Science Education, 22:9, p. 895-935, DOI: 10.1080/095006900416848

De Vries, M. J. (2013). *Modelling in technology and engineering education*. Paper presented at the PATT27, Christchurch, New Zealand. Retrieved from: https://ore.exeter.ac.uk/repository/bitstream/handle/10871/21615/PATT27%20Disruptive%20Technologies.pef?sequence=1#page=122

De Vries, M. J. (2018). Philosophy of technology: themes and topics. In M. de Vries (Ed.) *Handbook of Technology Education*. Springer International Handbooks of Education. DOI 10.1007/978-3-319-44687-5_1

Dym, C. L. (1994). *Engineering design: a synthesis of views.* Cambridge University press.

Esjeholm, B.-T., & Bungum, B. (2018). Linking knowledge and activities: How can classroom activities in technology reflect professional technological knowledge and practices? In M. de Vries (Ed.) *Handbook of Technology Education*. Springer International Handbooks of Education. DOI 10.1007/978-3-319-44687-5_42

Gibson, J. J. (1979). *The Ecological approach to Visual Perception*. Houghton Mifflin.

Gilbert, J., K. (2004). Models and Modelling: Routes to More Authentic Science Education. *International Journal of Science and Mathematics Education* 2, 115-130.

https://doi.org/10.1007/s10763-004-3186-4

Graneheim, U., H. & Lundman, B. (2004). Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today* 24(2), 105-112. https://doi.org/10.1016/j.nedt.2003.10.001

Gettie, D. & Wicklein. R. (2007). Curricular value and instructional needs for infusing engineering design into K-12 technology education. *Journal of technology Education, 19*(1), 6-18

Hallström, J. & Schönborn, K.J. (2019). Models and modelling for authentic STEM education: reinforcing the argument. *International Journal of STEM Education.* 6(22), p. 1-10. https://doi.org/10.1186/s40594-019-0178-z

Haupt, G. (2018). Design in technology education: current state of affairs. In M. de Vries (Ed.) *Handbook of Technology Education*. Springer International Handbooks of Education. DOI 10.1007/978-3-319-44687-5_48

Isa, S. S. & Liem, A. (2014). Classifying physical models and prototypes in the design process: A study on the economical and usability impact of adopting models and prototypes in the design process. In *DS 77: Proceedings of the DESIGN 2014 13th International Design Conference*.

Li, Y., Schoenfeld, A.H., diSessa, A.A. et al. Design and Design Thinking in STEM Education. *Journal for STEM Education Research 2*, 93–104 (2019). https://doi.org/10.1007/s41979-019-00020-z

Lewis T. (2005). Coming to terms with engineering design as content. *Journal of technology education, 16 (2),* 37-54

Mori, T. (2002). *Immaterial/Ultramaterial: Architecture, Design and Materials*. Harvard Design School/George Braziller

Mueller, R. A. (2019). Episodic Narrative Interview: Capturing Stories of Experience with a Methods Fusion. *International Journal of Qualitative Methods,* 18, 1–11. https://doi.org/10.1177/1609406919866044

Nia, M.G., de Vries, M.J. (2017). Models as artefacts of a dual nature: a philosophical contribution to teaching about models designed and used in engineering practice. *International Journal of Technology and Design Education,* 27, 627–653. https://doi.org/10.1007/s10798-016-9364-1

Norman, D. A. (1988). *The Psychology of Everyday Things*. Basic Books.

Norman, D. A. (2009). *The Design of Future Things*. Basic Books.

Norström, P. (2013). Engineers' non-scientific models in technology education. *International Journal of Technology and Design Education, 23*(2), 377-390. https://doi.org/10.1007/s10798-011-9184-2

Papanak, V., J. (2000). *Design for the real world: human ecology and social change*. Academy Chicago.

Perez, A. & Nord, A. (2021). Växthuset – från instruktion till lektion. *Teknikundervisning i skolan: Nyhetsbrev för teknikämnet i förskola, grundskola och gymnasium, 27*(2).

Potter, P., France, B. (2018). Influences of Materials on Design and Problem Solving Learning About Materials. In: de Vries, M. (eds) *Handbook of Technology Education*. Springer International Handbooks of Education. Springer, Cham. https://doi.org/10.1007/978-3-319-44687-5_35

Robson, C. & McCartan, K. (2016). *Real World Research*. 4th Ed. Wiley.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.

Skolinspektionen. (2014). *Teknik - gör det synliga osynligt. Om kvaliteten i grundskolans teknikundervisning.* Rapport 2014 (04)

Skolverket (2021). *In-depth texts on the central content of technology; Technology Development Work.* https://www.skolverket.se/download/18.189c87ae1623366ff377d70/1542293671159/teknikutvecklingsarbete.pdf

Skolverket (2022). *Läroplan för grundskolan, förskoleklassen och fritidshemmet 2022, Kursplan Teknik* https://ww.skolverket.se/undervisning/grundskolan/laroplan-och-kursplaner-for-grundskolan/laroplan-lgr22-for-grundskolan-samt-for-forskoleklassen-och-fritidshemmet?url=996270488%2Fcompulsorycw%2Fjsp%2Fsubject.htm%3FsubjectCode%3DGRGRTEK01%26tos%3Dgr&sv.url=12.5dfee44715d35a5cdfa219f

Telier, A., De Michelis, G., Ehn, P., Jacucci, G., Linde, P. & Wagner, I. (2011). *Design Things.* MIT Press.

Vetenskapsrådet (2017). *Good research practice* https://www.vr.se/download/18.5639980c162791bbfe697882/1555334908942/Good-Research-Practice_VR_2017.pdf

Welch, M. (1998). Students' Use of Three-Dimensional Modelling While Designing and Making a Solution to a Technological Problem. International Journal of Technology and Design Education, 8(3), 241-260. https://doi.org/10.1023/A:100880292

Wikberg-Nilsson, Å., Ericson, Å., Törlind, P. (2021). *Design-process och metod.* Studentlitteratur AB

Williams P. J. (2011). Engineering: good for technology education? In Vries, Marc. (2011). *Positioning Technology Education in the Curriculum,* 87-99, Sense Publishers. 10.1007/978-94-6091-675-5.

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27.3

Development of Students' Technical Abilities between 1993-2022 in Finnish Comprehensive Schools

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Abstract

The aim of this study was to find out if there have been any changes in technical abilities among Finnish school children during the last 30 years. Technical abilities were first measured in the affective, psychomotor, and cognitive areas in the year 1993 and these results were later compared with the results from 2012 and 2022. The number of test participants was 267 in the year 1993, 317 in 2012 and 282 in 2022. The age of the student respondents was 11–13 years. The measurements were done with exactly the same research instruments in all three years. Some positive changes were found in affective area among girls' test groups. Unfortunately, in all research groups the development was negative in the psychomotor and cognitive area. The reason for the decline could be in the reduction of craft and technology education lessons available, especially for boys. From a broader point of view, the changes can be due to the changes in society as a whole. It seems that the curriculum changes during last 30 years have not worked as they have been planned. Especially, boys underachievement is explained by the fact that, even if students work with systematic planning models and use their creativity, aesthetical design usually overshadows technological issues. It is assumed that progressive teaching and assessment favour girls and traditional methods are more congenial to boys.

Keywords

Technology education, Craft education, Curriculum, Technological abilities, Affective ability, Psychomotor ability, Cognitive ability.

Introduction

Between the years 1993 and 2022, there have been several changes in the national curriculum concerning technology education. The Framework Curriculum Guidelines (National Board of Education, 1994) for compulsory education states in its general section that the technical development of society makes it necessary for all citizens to have a new readiness to use technical adaptations and be able to exert an influence on the direction of technical development. Furthermore, students of any sex or gender must have the opportunity to acquaint themselves with technology and to learn to understand and avail themselves of technology. The curriculum also emphasizes that extensive knowledge is necessary when participating in technology-related discussions and problem solving. Moreover, in the general part of the curriculum, it is said that the ability to use different forms of technology, especially information and communication technology (ICT), gives students the chance to use the tools of modern society and, in general, offers a versatile environment for the understanding and the development of different forms of technology.

During 2001, there was an active discussion about the role of technology education in Finnish compulsory education. Spokespersons from industry were active in organizing national seminars for developing technology education in Finnish schools, especially the goals and content of technology education in the curriculum. Moreover, several projects aimed at developing the curriculum and technology education were started (Järvinen et al., 2000; Lavonen et al., 1998; Parikka, 1998; Santakallio, 1998.

The results obtained from the various development projects in the field of technology and from international discussion about the role of modern technology had an effect on the formulation of the goals and contents of technology education in the national curriculum framework for compulsory school (National Board of Education, 2004). Hence, the 2004 curriculum emphasized the meaning of technology from the point of view of everyday life, society, industry, and environment as well as human dependency on technology. Students should be familiar with new technology, including ICT, how it is developed, and what kind of influence it has. Students' technological skills should be developed through using and working with different tools and devices. Studying technology helps students to discuss and think about ethical, moral, and value issues related to technology. Although technology education was introduced for the first time in the framework curriculum, a separate technology education subject has not been established.

Since the national curriculum's (National Board of Education, 2004) emphasis on technology, the demand for technology as a school subject has increased considerably. However, in Finland the process proceeds with great difficulty, and it may take years before technology is taught to all pupils. The curriculum states that technical craft and textile craft should be compulsory for boys and girls in Grades 3–7. However, because of practical reasons such as timetabling and the number of teachers employed in many schools, students had to select just one of the craft subjects in 1993. As a consequence of this, most of the boys selected technical craft classes and girls joined textile education.

The latest Framework Curriculum Guidelines 2014 (National Board of Education, 2014) specified that in grades 1–9 technical craft and textile craft should be taught to both boys and girls throughout their entire compulsory schooling. The name for the subject was to be Handicraft and at a practical level, it is expected to create many changes. There are no separate subjects, just one multi material craft for both sexes. This means that there will be a minor emphasis on technology - art and design will be emphasized over technology education. Instead, the development of students' personalities, the growth of self-esteem and gender issues will be more important throughout the whole curriculum. There are expected to be many problems, as competence in different craft areas requires very different knowledge and skills; technological reasoning is based on very different scientific elements than aesthetical design.

What is more, during last year's there have been radical changes in craft teacher education. Based on gender equality there are no separate programs for technical craft teachers and textile craft teachers. The craft teachers have to master different contents and techniques in both technical and textile area. Unfortunately, the amount of ECTS credits is still the same as earlier although the students should master two different expertise areas. According to Kokko, Kouhia and Kangas (2020) confusion has occurred both in terms of the organization of the "new" subject that brings together the practices of textile and technical crafts, and the means and methods of craft education. Especially the new concept, multi-materiality, as well as the concept technology education, have been regarded problematic. Moreover, the changes and reduction in the distribution of the lesson hours have made the situation even more problematic. The main problem in Finland is that even though, now a days, there is more technology-related content that our children should be familiar with, the number of craft and technology lessons is still the same as 30 years ago, or even less and as a consequence of the latest curriculum girls have more technologically based lessons than 30 years ago. Unfortunately, boys have much less technologically based lessons than they had in 1993.

The main goal of this study was to find out if fundamental changes in students' technological abilities can be seen during the last 30 years. In order to evaluate students' technological abilities, research instruments were devised to measure cognitive, psychomotor, and affective areas of technology education. The main intention of the research was to compare the development between years 1993-2022. However, the comparison between boys and girls resulted in some new and interesting data.

The research questions were:

Are there differences in students' technological abilities in Finland between the years 1993 and 2022?

- in affective area
- in psychomotor area
- in cognitive area

Is there a difference between boys and girls in technological abilities?

Research Methodology

In the study, students' technological abilities were assessed with three different tests in: affective, psychomotor and cognitive areas. The main problem from the conception stage of the study was: how is technological ability to be defined and how can it be measured in a way that would be simple, easy to use with large groups, and still be reliable and valid enough to be generalized to other student populations? Furthermore, the test instrument needed to cover all three dimensions (cognitive, affective and psychomotor) of human personality, which are considered to be the outcomes of technology education. However, it is almost impossible to separate the dimensions, because in every psychomotor exercise there is a lot of cognitive thinking involved and in every cognitive act the affective domain is prominent.

To find out whether there were any differences between the measurements in 1993, 2012, and 2022 the researcher employed a two-tailed *t*-test with the same variance because there was no hypothesis of the development in technological abilities based on the previous research. Instead, boys and girls were compared with a one-tailed *t*-test in affective and cognitive areas because there is plenty of research evidence available about the difference. The number of test participants in the first measurement was 267 in year 1993, in the next measurement 317 in year 2012 and 282 in the final measurement in 2022. The age of the student respondents was 11–13 years. Approximately the same number of boys and girls as well as 11- and 13-year-old students took part in the study. In all samples (1993, 2012 and 2022), the schools were the same. Those schools were originally selected to ensure that schools with different curricula as well as rural and city schools were represented.

The first sample from 1993 was based on a research design in which different solutions for the practical implementation of technology education were tested. At that time, only a few schools were using a curriculum in which textile and technical craft was introduced to both boys and girls. These schools were selected for the sample from 1993, and the same schools were selected in 2012 and 2022. To ensure that different curriculum solutions and schools from rural and city areas were represented, some country schools were selected. These country schools used a traditional curriculum. In practice, this curriculum included traditional wood and metal work as well as engineering projects with electronics, mostly for boys, and textile education, mostly for girls. In 2012 and 2022, all schools with 11-year-old students had moved to a new curriculum that provided textile and technical craft for both boys and girls.

Despite the fact that skilled behaviour underlies nearly every human activity, our understanding about the factors that contribute to the attainment of expertise in technology education is far from complete. However, some attempts to define technological competence have been made. For example Dyrenfurth's (1990) and Layton's (1994) presented technological literacy as a relationship between technological will, technological skill and technological knowledge. Later on, for example Kimbell and Stables (2007) have developed the definition of technological capability with modern contents. For this research, Autio and Hansen (2002) defined technological competence as an interrelationship between technical abilities in affective, psychomotor and cognitive areas (*Figure 1*).

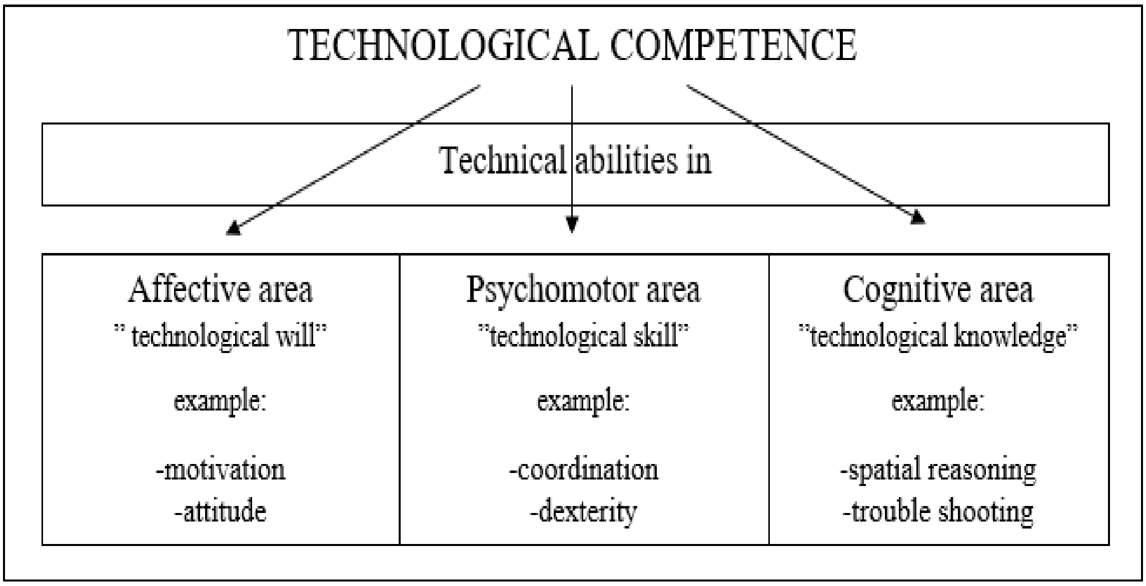


Figure 1. Technological competence

In order to evaluate students' *affective area*, a questionnaire was devised that consisted of 14 statements. For each Likert-type item, there were five options, from strongly disagree (1) to strongly agree (5). The questionnaire was based on the most common PATT (Pupils Attitudes Towards Technology) instrument, which was designed and validated by Raat and de Vries (1986) and van der Velde (1992). The original instrument, which consisted of 78 items, turned out to be too complicated and time consuming for 11- to 13-year-old students. Hence, for this study, a shorter version of attitude questionnaire was developed. The researcher removed many items that had small item-rest correlation (i.e., correlations between item score and total score of the rest of the scale). Finally, the questionnaire consisted of the following six factors: interest in technology, consequences of technology, difficulty of technology, role pattern, technological career, and technology as school subject. According to the researcher's observations, it was easy to use and not time consuming. In addition, the students could fully concentrate on answering of all items. Reliability of the questionnaire was 0.85 in 1993.

Instead of just comparing boys' and girls' attitudes, the underrepresentation of girls and women in science, technology, engineering, and mathematics (STEM) is a much more common research area (Burke & Mattis, 2007; Ceci, Williams & Barnett, 2009; Ceci & Williams, 2011; Cheryan et al., 2017). Hence, more attention should be paid to girls' subjective task value ranking for math and science relative to their ranking of other subjects such as reading and language skills (Klein et al., 2007). Even if women are more interested in other fields, it does not mean that they could not be equally interested in engineering (Cheryan et al., 2017).

There has been much interest in constructing theoretical conceptions of the dynamic's psychomotor performance. However, the analysis of motor abilities suggests that any process description is more complex than has yet been explicitly admitted. First, such descriptions must be more complex because of the large number and the wide range of dimensions that are needed in order to fully characterize individual difference in the motor domain. According to Powell et al. (1978) there are several compatible ways of describing the varied structural components of the motor system. From the standpoint of factor analysis, they represent hierarchically organized dimensions of individual differences; from the viewpoint of information processing theory, they represent decomposable classes of general motor programs or classes of parameters entailed by those programs, and from the perspective of general systems theory, they can be construed as hierarchically decomposable systems and subsystems (*Figure 2*.)

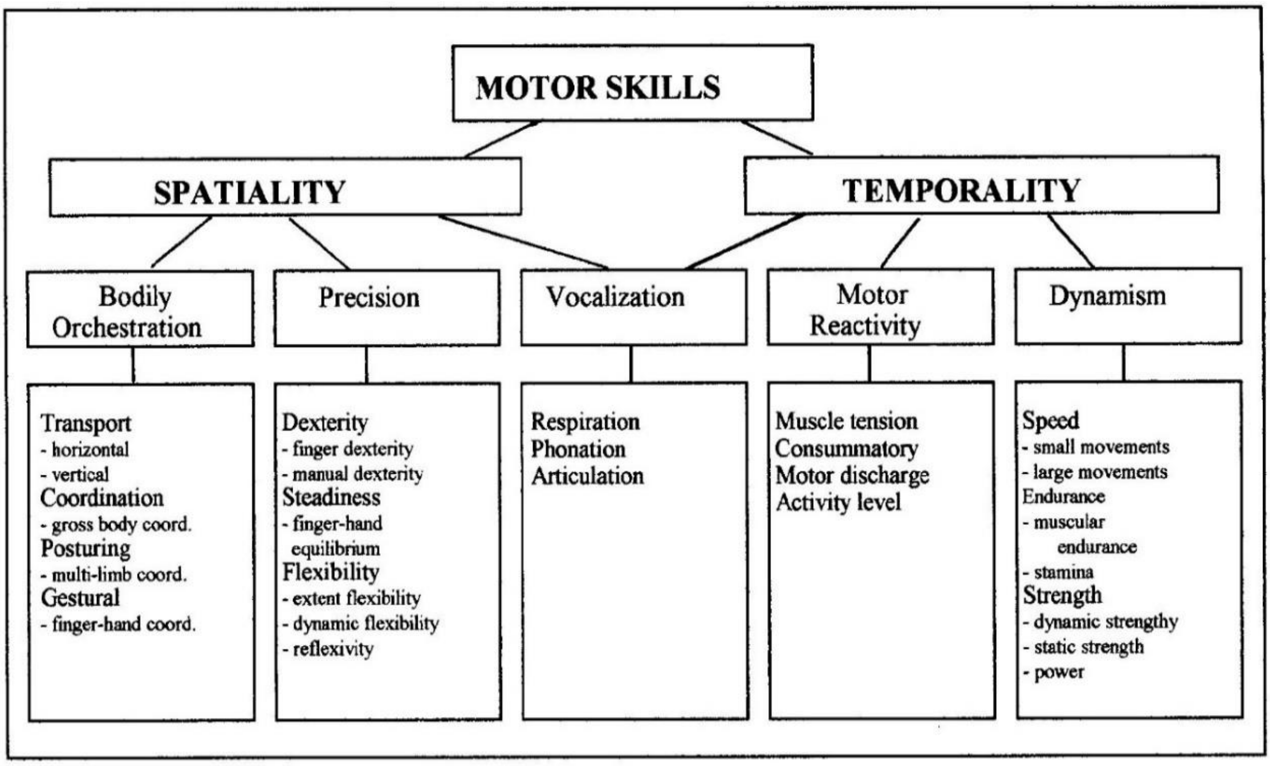


Figure 2. The hierarchical factor system of motor skills modified from (Powell & al. 1978).

In the *psychomotor area* the test was called X-boxes and it was based on the theory of Powell et al. (1978). In this test of motor skills all the elements of bodily orchestration, precision, motor reactivity and dynamism are involved. The task in the measurement was to build up as many x-box (*Figure 3*.) as possible in five minutes. The reliability of this test was 0.819 as measured with the Cronbach Alpha.

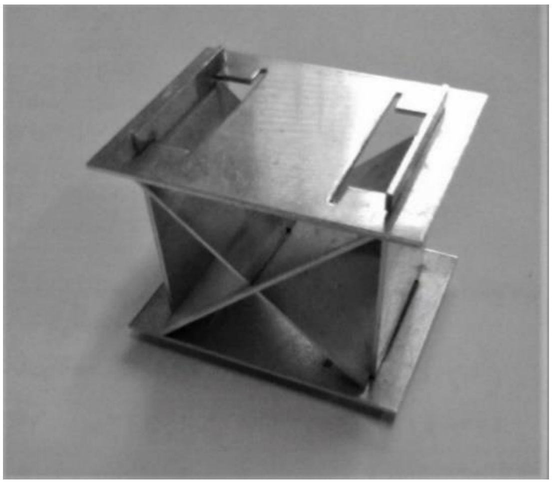


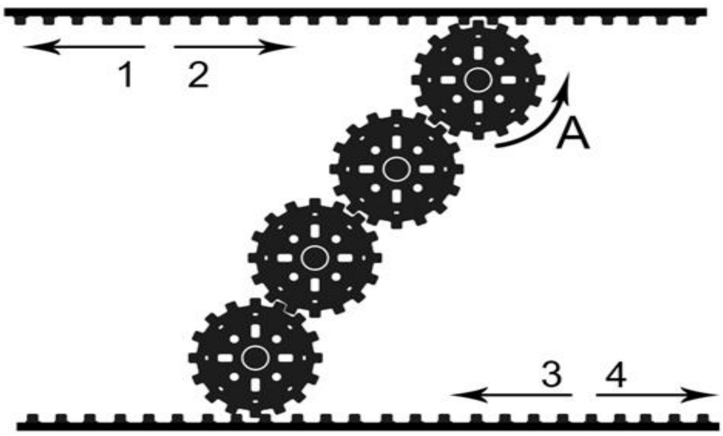
Figure 3. X-box

Technological knowledge is important for students, in rationalising the changing world of today. Furthermore, as active citizens, it enables them to play a part in the modification of the environment. Technology can be described by means of how humans modify the world around them in order to meet their needs and solve practical problems (Maryland Technology Literacy Consortium, 2014). It extends human possibilities and enables people to do things they could not otherwise do. Technological action focuses on fulfilling specific goals under the influence of a variety of factors, such as individual, group or societal needs and the development of components, devices and systems.

Technological understanding and reasoning have been examined within the context of technology and science education and some scholars claim that, if students are to successfully learn about science and technology, they must be aware of the different concepts and processes. To understand the relationship between these, they need to have technological knowledge, which is based on technological reasoning (Hubber et al., 2010; Prain et al., 2009).

Kohl et al. (2007) suggested that the ability to demonstrate is a key in studying physical science. Mental rotation involves the ability to look at a picture of an object and visualize what it might look like when rotated in three-dimensional space. This skill relates to the ability on how mentally transform images. This is useful in a variety of tasks, such as carpentry, architecture, map reading, engineering, and sports.

In the *cognitive area*, the test instrument was called 'a test of technological knowledge and reasoning'. It consists of 28 questions. The questions deal mainly with physical laws, often observed in simple machines. Other aspects of technical knowledge are also involved, e.g., tool design and application. The reliability of the test in 1993, measured with the Cronbach Alpha, was 0.881. An example question can be seen in *Figure 4.*



If cogwheel A turns to the direction of arrow, in what direction do the cog levers move?
1) Direction 1 and 3
2) Direction 1 and 4
3) Cog levers cannot move

Figure 4. Example questions in cognitive area – technological reasoning

Results

Affective area

In the affective area a statistically very significant ($p<0.001$) difference was found between years 1993-2022 among 11-year-old girls as the result was 2.88 in the year 1993 and 3.37 in 2012 and 3,41 in 2022. Similarly, but a smaller development was found in 13-year-old girls test group. The difference between years 1993 (2.90), 2012 (3.14), and 2022 (3.21) was also statistically very significant ($p<0.001$). Among the boys' test groups, the results followed the same pattern as those of the girls during years 1993-2012. However, noticeable decline was found between years 2012-2022. The figures were (3,59 / 3,78 / 3,60) among 11-year-old boys and (3,51 / 3,72 / 3,51) among 13-year-old boys. Standard deviation remained quite stable in all test groups. However, in the year 1993 it was usually higher than in 2012 and 2022. In addition, there was a noticeable difference between younger (0.75) and older (0.46) girls in the year 1993. Average values and standard deviation in 1993, 2012, and 2022 among boys and girls test groups in the measurement of affective area is presented in *Table 1*.

Attitudes are assumed to be rather stable during the school years (Arffman & Brunell, 1983; Bjerrum Nielsen & Rudberg, 1989; Autio, 2013). This was expected to be the case in this research as well and in the measurement of 1993 the result of 11-year-old girls was 2,88 and 13-year-old girls 2,90. However, in years 2012 and 2022 the result was better among 11-year-old girls (3,37/3,41), as 13-year-old girls had 3,14/3,21. Among younger and older boys' similar difference was not noticed.

Table 1. Average values and standard deviation in 1993, 2012, and 2022 in the measurement of affective area

	1993		2012		2022		1993-2022
Group	***M***	***SD***	***M***	***SD***	**M**	**SD**	***p*-value**
11-year-old girls	2,88	0,75	3,37	0,56	3,41	0,55	$p<0.001$***
11-year-old boys	3,59	0,69	3,78	0,48	3,60	0,54	$p = 0.49$
13-year-old girls	2,90	0,46	3,14	0,52	3,21	0,52	$p< 0.001$***
13-year-old boys	3,51	0,69	3,72	0,56	3,51	0,55	$p = 0.46$

Although the difference between boys and girls in the affective area was smaller in 2022 than 1993, statistically very significant difference (p<0.001) was found. The difference between boys' and girls' attitudes was not surprising because similar results have been reported already 30 years ago in several studies (Allsop 1986; Autio, 1997; Autio & Soobik, 2013; de Klerk Wolters, 1989; Grant & Harding, 1987; Johnson & Murphy, 1986; Streumer, 1988). Nowadays, the difference between boys and girls has been accepted and more attention has been paid to the underrepresentation of girls and women in science, technology, engineering, and mathematics (Burke & Mattis, 2007; Ceci et al., 2009; Ceci & Williams, 2011; Cheryan et al., 2017; Stoet & Geary, 2018). The difference in research groups between the years 1993, 2012 and 2022 in the measurement of affective area is presented in *Figure 5.*

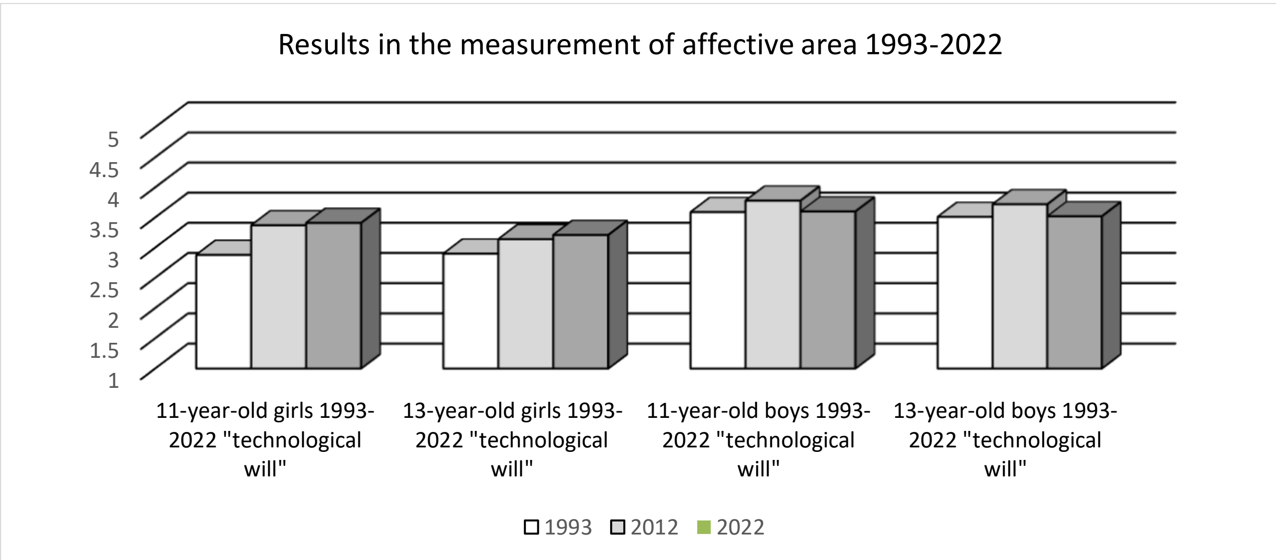


Figure 5. Difference in research groups between the years 1993, 2012 and 2022 in the measurement of affective area

The highest correlation (0.76, p<0.001***) to the average of all other statements was found in statement 1: I am interested in technology and the phenomena related to it. In the factor analysis, this statement explained 57.7 % of the total variance. Very significant statistical difference was found in 11-year-old girls test group as the result was 2,53 in year 1993, 3,43 in year 2012 and 3,64 in 2022. Unfortunately, in 13-year-old girls test group the development was diminished, as the result was 3,00 in year 1993, 2,97 in year 2012 and 2,95 in 2022. Among 11 and 13-year-old boys just small changes was found between years 1993-2022, as 11-year-old boys had 4,01 in year 1993, 4,34 in year 2012 and 4,16 in 2022. In 13-year-old boys test group the small development was diminished, as the result was 3,95 in year 1993, 4,07 in year 2012 and 3,88 in 2022. The average values for statement 1: I am interested in technology and the phenomena related to it are presented in *Figure 6.*

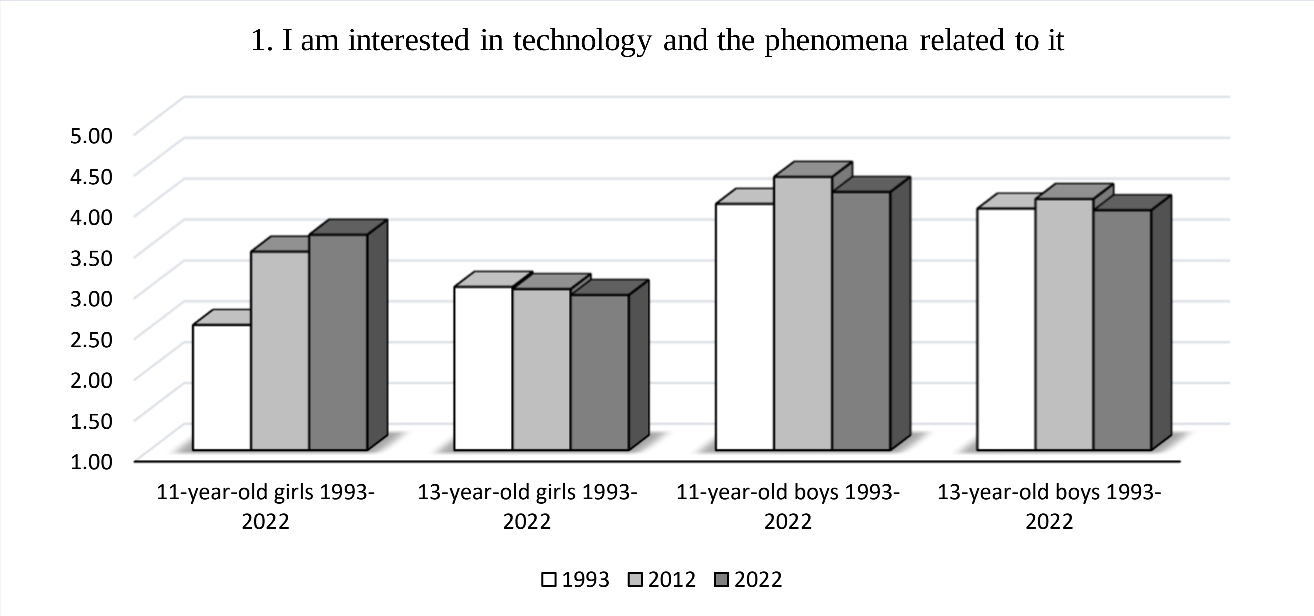


Figure 6. Difference in research groups between the years 1993, 2012 and 2022 in the statement: I am interested in technology and the phenomena related to it

Psychomotor area

In the psychomotor area a statistically significant difference was found among all test groups between years 1993-2022. Among 13-year-old boys the result dropped down from 4,52 in the year 1993 to 4,02 in 2012 and finally 3,25 in the measurement of 2022. The result was quite similar among 13-year-old girls. In the year 1993 the result was 4.50, 4,06 in the year 2012 and 3,17 in 2022. The results followed the same pattern among 11-year-old boys. In the year 1993 the result was 3,41, 3,12 in 2012, and 2,16 in 2022. Among 11-year-old girls' test groups similar decline was found between years 1993-2012 as the result was 2,84 in the year 1993 and 2,36 in 2012. Instead, a small positive change was found between years 2012-2022 as the result was 2,40 in the year 2022. Standard deviation was quite stable in all test groups. However, it was a bit lower in the 2012 and 2022 measurements. Average values and standard deviation in 1993, 2012, and 2022 among boys and girls test groups in the measurement of psychomotor area are presented in *Table* 2.

Table 2. Average values and standard deviation in 1993, 2012, and 2022 in the measurement of psychomotor area

Group	1993		2012		2022		
	M	*SD*	*M*	*SD*	M	SD	*p*-value
11-year-old girls	2,84	1,87	2,36	1,56	2,40	1,48	$p = 0.09$**
11-year-old boys	3,41	1,86	3,12	1,68	2,16	1,63	$p < 0.001$***
13-year-old girls	4,50	2,11	4,06	1,91	3,17	2,01	$p < 0.001$***
13-year-old boys	4,52	1,96	4,02	1,93	3,25	1,69	$p<0.001$***

It was quite obvious that there was a difference between younger (11-year-old) and older (13-year-old) students. This is most probably due to normal maturation and transfer from hobbies. In practice there was no difference between boys and girls in the psychomotor area. It seems that both textile – and technical craft place equal emphasis on psychomotor skills. However, the difference between 11-year-old boys and girls in the measurement of 2022 needs to be researched further, because it is possible that the lower level of technological reasoning among girls' test group may have had an impact on the performance in psychomotor test during years 1993-2012. Maybe, the direction changed between years 2012-2022 due to boys decline in technological reasoning. It is obvious that in every psychomotor action some elements of cognitive area are needed. In this case 3-dimensional perceptive skills may be the distinctive factor. Difference in research groups between the years 1993, 2012 and 2022 in the measurement of psychomotor area is presented in *Figure 7.*

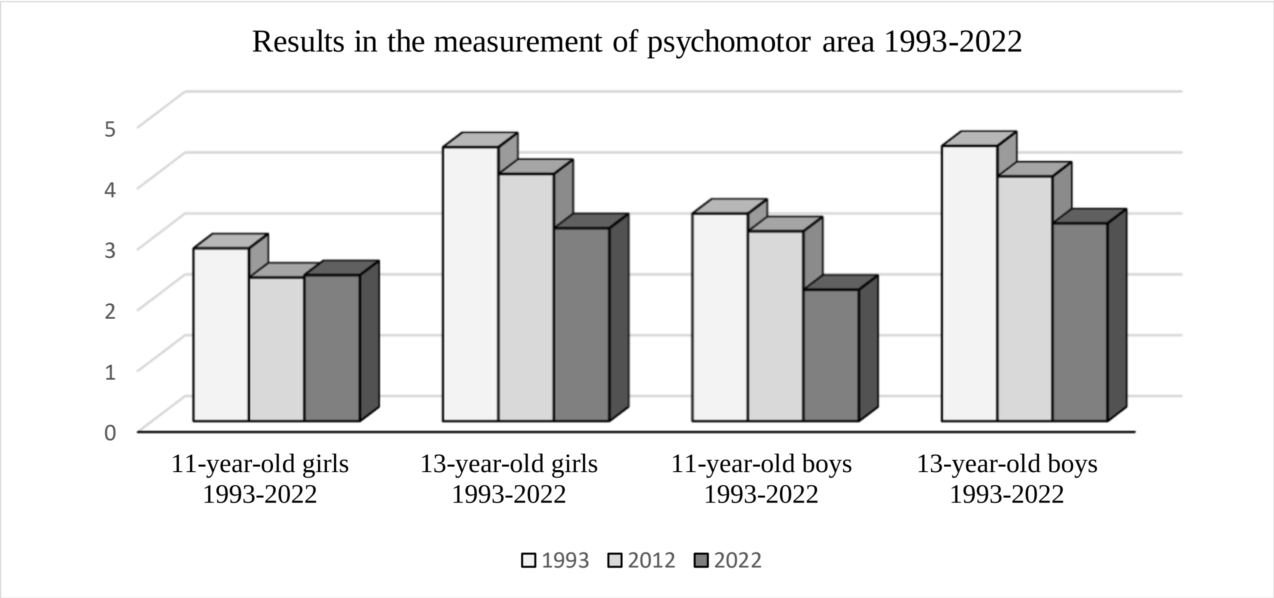


Figure 7. Difference in research groups between the years 1993, 2012 and 2022 in the measurement of psychomotor area

Cognitive area

In the cognitive area a statistically very significant (p<0.001) difference was found between years 1993-2022 among all test groups, except 11-year-old girls. The average number of correct answers to 28 questions among 13-year-old boys dropped down from 18.5 in the year 1993 to 16.5 in 2012 and finally 14,4 in the measurement of 2022. The difference was quite similar among 11-year-old boys. In the year 1993 the number of correct answers was 15.8, 14.9 in 2012, and 12,8 in 2022. Among 11-year-old girls' test groups in practice no difference was found as the result was 12.9 in the year 1993, 12.6 in 2012 and 12,5 in 2022. Similarly, no difference was found among the older girls between years 1993-2012 as the result was 15.3 in the year 1993 and 15.2 in 2012. However, noticeable decline was found between years 2012-2022 as the result was only 13,5 in the year 2022. Standard deviation was a bit lower among younger girls in 1993 (2,87) than in 2022 (3,59). Among older girls the figure was in 3,9 in 1993 and 3,08 in 2022. Among boys' test groups standard deviation was quite stable during years 1993-2022. Average values and standard deviation in 1993, 2012, and 2022 among boys and girls test groups in the measurement of cognitive area are presented in *Table* 3.

Table 3. Average values and standard deviation in 1993, 2012, and 2022 in the measurement of cognitive area

Group	1993		2012		2022		1993-2022
	M	***SD***	***M***	***SD***	**M**	**SD**	***p*-value**
11-year-old girls	12,9	2,87	12,6	3,47	12,5	3,59	p = 0.24
11-year-old boys	15,8	4,59	14,9	3,96	12,8	3,8	p<0.001***
13-year-old girls	15,3	3,9	15,2	4,14	13,5	3,08	p<0.001***
13-year-old boys	18,5	3,56	16,5	3,83	14,4	3,81	p<0.001***

As expected, it was quite obvious that there was a difference between younger (11-year-old) and older (13-year-old) students. This is most probably due to normal maturation caused by the number of lessons in two years concerning technology education. Transfer from hobbies and the use of technology related textbooks in other subjects is assumed to be another reason.

It is not a surprise that boys and girls differ in their interests and hobbies. This maybe the reason for the male advantage in mental rotation performance that represents one of the most robust gender differences in adult cognition. The developmental trajectory of this male advantage remains a topic of considerable debate (Lauer et al., 2019). In any case, statistically significant differences (p<0.001) between boys and girls were found. This difference in technological knowledge, especially in spatial reasoning corroborates with several other research (Autio, 1997; Autio & Soobik, 2013; Johnsson & Murphy, 1986; Lauer et al., 2019; Linn & Petersen, 1985; Streumer, 1988; Tzuriel & Egozi, 2010; Voyer et al., 1995; Yang, & Chen, 2010). However, we must consider that spatial skills and technological reasoning consistently improve with a simple training course, and they are mostly due to previous experience in design-related courses, as well as play with construction toys such as Legos (Sorby &

Baartmans, 2000; Tzuriel & Egozi, 2010; Yang, & Chen, 2010). Difference in research groups between the years 1993, 2012 and 2022 in the measurement of cognitive area is presented in *Figure 8.*

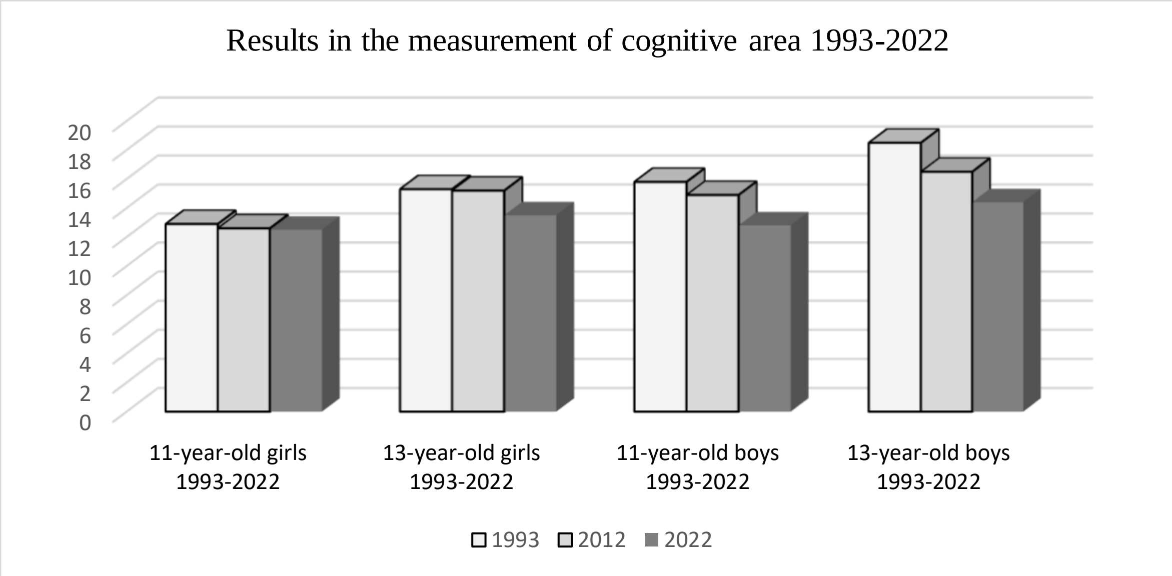


Figure 8. Difference in research groups between the years 1993, 2012 and 2022 in the measurement of cognitive area

Discussion

The critical side from the conception stage of this study was: how is technological ability to be defined and how can it be measured in a way that would be simple, easy to use with large groups, and still be reliable and valid enough to be generalized to other student populations? Moreover, to achieve a relevant comparison, the measurements were made with exactly the same test instruments in 1993, 2012 and in 2022. Because the test instruments should be the same during all measurements, they could not be updated during the last 30 years. Hence, it is possible that in the test of technological knowledge and reasoning some of the questions may have been old-fashioned for students in the year 2022. In addition, we must consider that the whole technological landscape has changed over time and today includes technology that did not exist 30 years *ago.* In the future, the questionnaire needs to be improved and the content needs to be updated with modern contents. In addition, some criticism could be raised because the selection of the schools was made already in 1993 and the sample was discretionary rather than incidental. However, the difference between schools in Finland is very small, as reported in the 2012 PISA results (Kupari et al., 2013).

The most alarming result in this research was that students did not perform in the measurement of technical knowledge and reasoning (cognitive area) as well as expected. Among 13-year old boys the average number of correct answers to 28 questions dropped down from 18.5 to 14.4 during years 1993-2022. The difference was quite similar among 11-year-old boys. In the year 1993 the number of correct answers was 15.8 and 12.8 in 2022. Among younger girls' test group in practice no difference was found, as 11-year-old girls scored 12.9 in the year 1993 and 12.5 in 2022. However, statistically very significant difference was found among the older girls, as they had 15.3 correct answers in the year 1993 and 13.5 in 2022.

Another fact was that results in psychomotor area among 13-year-old boys dropped down from 4,52 in the year 1993 to 3,25 in the measurement of 2022. The results followed the same pattern among 11-year-old boys. In the year 1993 the result was 3,41, and only 2,16 in 2022. The result was quite similar among 13-year-old girls. In the year 1993 the result was 4.50, and 3,17 in 2022. Among 11-year-old girls' test groups similar decline was found between years 1993-2012 as the result was 2,84 in the year 1993 and 2,36 in 2012. Instead, a small positive change was found between years 2012-2022 as the result was 2,40 in the year 2022.

Reasons for the decline could be in the reduction of technology education lessons available especially for boys. Instead, girls have more technology related lessons than they had 30 years ago. Unfortunately, this is not directly seen in this research. Maybe because, in combined craft education (as much textile and technical craft) learning is focused on production skills and lessons are mainly based on reproducing artefacts without a connection with technological knowledge and reasoning. Other researchers state that the real problem for boys' underachievement is the radical shift in teaching methods and in the content of the school curriculum that progressive education has wrought. It is assumed that progressive teaching and assessment favour girls and traditional methods are more congenial to boys (Attarian, 2000; Ward, 2000).

The most promising result was that girls' attitudes towards technology were definitely more positive in 2022 than in 1993. The average response in our Likert-style (1–5) questionnaire to all 14 items among 11-year-old girls was 2.88 in 1993 and 3.41 in 2022. Among 13-year-old girls' direction was the same, as the result was 2,90 in 1993 and 3,21 in 2022. However, the development between years 2012 and 2022 was much smaller. Although the development in boys test groups remained quite stable during years 1993-2022, it can be concluded that the positive development was because of changes in the technological environment in general. There are plenty of different technological solutions (e.g., mobile phones, games consoles, tablets, interestingly themed construction kits) available for all children nowadays that did not exist 30 years ago. This will be a challenge for the curriculum development in the future. How can technology education benefit from the fact that especially girls are interested in technological everyday solutions rather than technological details, as reported in several other studies (Eccles, 2009; Mitts, 2008; Weber & Custer, 2005; Wender, 2004).

According to several international studies measuring proficiency in natural sciences and mathematics, Finnish girls have been outperforming boys both in mathematics and natural sciences since 2015 (Leino et al., 2018; Stoet & Geary, 2018). On the other hand, Finnish girls are still far less interested in engineering and technology than boys. Current intervention efforts and projects in Finland assume that enhancing girls' interest in natural sciences and mathematics will also lead to an increasing interest in technology and engineering. However, these efforts have not had a significant impact on the underrepresentation of women in engineering/technology. Paradoxically, countries with high levels of gender equality have some of the largest STEM gaps in secondary and tertiary education. For example, Finland excels in gender equality (World Economic Forum, 2015).

Therefore, instead of to encouraging more girls to study science and technology it is also necessary to help girls to better understand what engineering and development of technology are about. However, this is not primarily a question of giving young people information but rather a question of creating a wider disciplinary self-understanding. This requires a cultural change and critical contemplation of values as suggested by Ulriksen et al. (2010). Engineering has several subdisciplines that attract women more than others. Design and human technology are central aspects in any field of engineering. Thus, these areas should be considered consistently throughout the field instead of using them to create “female-friendly” subdisciplines, which easily become devalued as softer or “imaginary” engineering (Naukkarinen & Bairoh, 2020)

Nevertheless, from an intra-individual perspective, boys and girls have different patterns in how they prioritize math and science in relation to other subjects, which indeed exhibit the power of person-cantered approaches. Even if boys and girls have started to place similar values on math and science, the two gender groups still vary in how they rank math and science in relation to other school subjects. Hence, more attention should be paid to girls’ Subjective task value (STV) ranking for math and science relative to their ranking of other subjects, if the problem of the gender imbalance in the physical science fields is to be remedied (Klein et al., 2007).

During last thirty years there has been an active discussion about the role of technology education in Finnish compulsory education. However, the optimal solution on how technology education could be realised in practice proceeds with great difficulty. Among public servants, office holders and teachers as well as researchers or teacher educators a consensus has not been found. Others think that technology education should be design-process based with the emphasis on wood and metal work and others feel it should be a more theoretical "classroom-type" school subject. Moreover, the basic concepts, contents and the relationship between craft and technology are not clear for all parties.

Conclusions

The Finnish curriculum has put large emphasis on gender equity since 1970. Hence, it is confusing that the development in attitudes towards technology proceeds with great difficulty. Finnish girls seemed to be aware of the gender equity and they highly agree that both boys and girls may understand engineering-related phenomena. However, only a few girls are willing to challenge stereotypes about non-traditional careers for women (Autio, Soobik, Thorsteinsson & Olafsson, 2015). It can be concluded that an ideal solution in Finnish technology education has not been found. NBE (2014) states that even the name for the subject is changed to Handicraft, which means that there is a minor emphasis on technology. Instead, the development of students’ personalities, the growth of self-esteem and gender issues are considered to be more important in the curriculum. Unfortunately, we cannot measure our students’ development in these areas with reliable methods. However, in Pisa studies a serious decline has been noticed in several areas. In natural sciences, Finnish result was 563 in 2006 and 531 in 2016 (Leino et. al, 2018)

Several development projects are made to promote interest in technology. According to Mammes (2004) attitudes towards technology can be significantly improved by developing special courses just for girls. “Because technology education has traditionally been such a male-oriented subject, teachers need to be aware of the differing interests of girls and consider ways of making the environment and the subject attractive to them “(Silverman & Pritchard, 1996). Furthermore, some researchers believe that “in school situations where only females are present, the gender-related segment becomes relatively inactive, and interests could develop independently. So, if girls' interests should be turned to technology (against the gender stereotype), gender separate teaching is advisable" (Wender, 2004). In addition, several preconditions are recommended such as support from female role models and an atmosphere that encourages confidence and inclusion of technical problems in everyday situations that have a relationship with people (Häussler & Hoffmann, 1998). For example, teaching math, chemistry, and physics using more biologically based metaphors and a more real-world problem-oriented approach have been shown to increase female students' interest in physics (Klein et al., 2007

As we try to develop technology education in the future, it would be advisable that in the beginning, every student should be given the basic skills required in everyday life situations in both traditional craft and technology education but later on every student must also be given an opportunity to concentrate more seriously on the area in which they are most interested. In addition, the difference between boys and girls in technological knowledge and attitude must be considered by designing technology studies for different genders in a particular age group. As early as in the nursery school, teachers may need to concentrate more on crafts that place more emphasis on mechanics than just soft materials.

During last 30 years, hundreds of different development projects have been made all over the world and in Finland gender equity in technology education has been one main theme since 1970. The results of this research show some positive signs in girls' attitudes towards technology. However, the results in other areas are not as promising and it can be concluded that an ideal solution in Finnish technology education has not been found. The problem of the inequality in the field of technology seems to be far more complicated than we used to think. It is not just technology education that is responsible for solving such a complex problem but society as a whole.

References

Allsop, T. (1986). Attitude studies in the OERG Technology project. In J. H. Raat & M. J. de Vries (Eds.), *What do boys and girls think of technology? Report PATT' workshop* (pp. 147–150). Eindhoven, the Netherlands: Eindhoven University of Technology.

Arffman, I. & Brunell, V. (1983). *Sukupuolten psykologisista eroavaisuuksista ja niiden syistä [Psychological gender differences and the reasons for them]*. Jyväskylän yliopisto. Kasvatustieteiden tutkimuslaitoksen selosteita ja tiedotteita 283.

Attarian, J. 2000. Let boys be boys. *World and I, 15*(10): 238.

Autio, O. (1997). *Oppilaiden teknisten valmiuksien kehittyminen peruskoulussa [Student's development in technical abilities in Finnish comprehensive school*]. Research Reports No. 117. Helsinki: The University of Helsinki, Department of Teacher Education.

Autio, O., & Hansen, R. (2002). Defining and Measuring Technical Thinking: Students Technical Abilities in Finnish Comprehensive Schools. *Journal of Technology Education 14 (1)*, 5–19.

Autio, O. (2013) Oppilaiden teknologiset valmiudet – vertailu vuoteen 1993. [Students' technological abilities – a comparison to a year 1997] *Kasvatus 44 (4),* 367-380.

Autio, O & Soobik, M. (2013). A Comparative Study of Craft and technology Education Curriculums and Students' Attitudes towards Craft and Technology in Finnish and Estonian Schools. *Techne series A, 20* (2), 17-33.

Autio, O., Soobik, M. ,Thorsteinsson, G. & Olafsson, B. (2015). The Development of Craft and Technology Curriculums and Students' Attitudes towards Technology in Finland, Estonia and Iceland. *International Journal of Contemporary Educational Research 2(1),* 22-34.

Bjerrum Nielsen, H. & Rudberg, M. (1989). *Historien om jenter og gutter. Kjonnsosialisering i ett utvecklingspsykoligisk perspektiv*. Oslo: Universitetslaget

Burke, R.J., & Mattis, M.C. (2007). Women and minorities in science, technology, engineering, and mathematics: upping the numbers. Cheltenham, UK: Edward Elgar Publishing Limited.

Ceci, S.J. & Williams, W. M. (2011). Understanding current causes of women's underrepresentation in science. PNAS, 108(8), 3157-3162.

Ceci, S.J., Williams, W. M., & Barnett, S.M. (2009). Women's underrepresentation in science: Sociocultural and biological considerations. Psychological Bulletin, 135(2), 218-261.

Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological Bulletin*, 143(1), 1–35.

de Klerk Wolters, F. (1989). *The attitude of pupils towards technology.* Eindhoven, the Netherlands: Technische Universiteit Eindhoven.

Dyrenfurth, M. J. (1990). Technological Literacy: Characteristics and Competencies, Revealed and Detailed. In H. Szydlowski & R. Stryjski (Eds.) *Technology and School: Report of the PATT Conference* (pp. 26-50). Zielona Gora, Poland: Pedagogical University Press.

Eccles, J. (2009). Who Am I and What Am I Going to Do with My Life? Personal and Collective Identities as Motivators of Action. Educational Psychologist 44(2), 78-89.

Grant, M., & Harding, J. (1987). Changing the polarity. *International Journal of Science Education*, *9*(3), 335–342

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: pedagogy and teacher change. *Research in Science Education, 40*, 5-28.

Häussler, P., & Hoffmann, L. (1998). Qualitative differences in students' interest in physics and the dependence on gender and age. In L. Hoffmann, A. Krapp, K. A. Renninger, & J. Baumert (Eds.), *Interest and learning: Proceedings of the Seeon Conference on Interest and Gender* (pp. 280–289). Kiel; Germany: IPN.

Johnson, S., & Murphy, P. (1986). *Girls and physics: Reflections on APU survey findings* (APU Occasional Paper No. 4). London, England: Department of Education and Science.

Järvinen, E.M., Lindh, M. and Sääskilahti, E. (2000). *Planning a New Technology Education Centre in Finland: An Investigation of the Need for Systematic In-Service Training Activities on Technology Education*. A paper presented at the PATT-10 Conference in Salt Lake City, 6th -8th April 2000.

Kimbell, R. & Stables, K. (2007). *Researching Design Learning: Issues and findings from two decades of research and development.* Springer.

Klein, S. S., Richardson, B., Grayson, D. A., Fox, L. H., Kramarea, C., Pollard, D. S., & Dwyer, C. A. (2007). *Handbook for achieving gender equity through education.* New York, NY: Routledge.

Kohl, P., Rosengrant, D. & Finkelstein, N. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physics Review Special Topics - Physics Education Research, 3*, 1-10.

Kokko, S., Kouhia, A. & Kangas, K. (2020). Finnish craft education in turbulence. Conflicting debates on the current National Core Curriculum. Techne Series A: 27(1), 1–19.

Kupari, P., Välijärvi, J., Andersson, L., Arffman, I., Nissinen, K., Puhakka, E., & Vettenranta, J. (2013). *PISA 12 ensituloksia* [PISA 12 preliminary results]. Helsinki, Finland: Opetus- ja kulttuuriministeriö [Ministry of Education and Culture].

Lauer, J., Yhang, E., & Lourenco, S. (2019). The development of gender differences in spatial reasoning: A meta-analytic review. *Psychological Bulletin* 145(6), 537-565.

Lavonen, J., Meisalo, V., Autio, O., & Lindh, M. (1998). *Teaching basics of electricity and electronics in school laboratory* (Research Report No. 193). Helsinki, Finland: University of Helsinki, Department of Teacher Education.

Layton, D. (1994). A School Subject in the Making? The Search for Fundamentals. In D. Layton (Ed.) *Innovations in Science and Technology Education* (Vol.5). Paris: Unesco.

Leino, K., Ahonen, A., Hienonen, N., Hiltunen, J., Lintuvuori, M., Lähteinen, S., Lämsä, J., Nissinen, K., Nissinen, V., Puhakka, E., Pulkkinen, J., Rautapuro, J., Siren, M., Vainkainen, M-P., & Vettenranta, J. (2018). *PISA 18 ensituloksia* [PISA 18 preliminary results]. Helsinki, Finland: Opetus- ja kulttuuriministeriö [Ministry of Education and Culture].

Linn, M. & Petersen, A. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*(6), 1479–1498.

Mammes, I. (2004). Promoting Girls' Interest in Technology through Technology Education: A Research Study. *International Journal of Technology and Design Education 14*, 89-100.

Maryland Technology Literacy Consortium (2014). Maryland Technology Literacy Standards for Students. Professional Development and Technology Measures for Students, Teachers and School Administrators. Retrieved 12 May 2014 from: http://www.montgomeryschoolsmd.org/departments/techlit/

Mitts, C. R. (2008). Gender preferences in technology student association competitions. *Journal of Technology Education*, *19*(2), 80–93.

National Board of Education (1994). *Framework curriculum for the comprehensive school (in Finland)*, Helsinki: State Printing Press and National Board of Education

National Board of Education (2004). *Framework curriculum for the comprehensive school (in Finland)*, Helsinki: State Printing Press and National Board of Education

National Board of Education (2014). *Framework curriculum for the comprehensive school (in Finland)*, Helsinki: State Printing Press and National Board of Education

Naukkarinen, J. & Bairoh, S. (2020). STEM: A help or a hinderance in attracting more girls to engineering? *Journal of engineering education, 109(2*), 177–193.

Parikka, M. (1998). *Teknologiakompetenssi. Teknologiakasvatuksen uudistamishaasteita peruskoulussa ja lukiossa.* (Technological competence: Challenges of Reforming Technology Education in Finnish Comprehensive and Upper Secondary School). Jyväskylä Studies in Education, Psychology and Social Research 141

Powell, A., Katzko, M., Royce, J. (1978). A Multifactor system theory of the structure and dynamism. *Journal of Motor behaviour, 194-200.*

Prain, V., Tytler, R. & Peterson, S. (2009). Multiple representation in learning about evaporation. *International Journal of Science Education, 31*(6), 787–808.

Raat, J. & de Vries, M. (1986). *What do Girls and Boys think about Technology?* Eindhoven, University of Technology.

Santakallio, E. (1998). Teknologiakasvatusta käsityökasvatuksen kontekstissa: Opetus- ja koulutusteknologian integrointi teknisen työn opintoihin Kajaanin opettajankoulutuslaitoksessa [Project for developing entrepreneurship and technology education in the Kainuu region]. In T. Kananoja, J. Kantola, & S. Issakainen (Ed.), *Development of technology in education conference* (pp. 273–280). University of Jyväskylä.

Silverman, S. & Pritchard, A. (1996). Building Their Future: Girls and Technology Education in Connecticut, *Journal of Technology Education* 7 (2), 41-54.

Sorby, S. & Baartmans, B. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education, 89*(3), 301–07.

Stoet, G., & Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological Science*, 29(4), 581–593.

Streumer, J.H. (1998). *Evalueren van techniek.* Encshede: Universiteit van Twente.

Tzuriel, D. & Egozi, G. (2010). Gender Differences in Spatial Ability of Young Children: The Effects of Training and Processing Strategies. *Child Development 81(5),* 1417-1430.

Ulriksen, L., Møller Madsen, L., & Holmegaard, H. T. (2010). What do we know about explanations for drop out/opt out among young people from STM higher education programmes? *Studies in Science Education*, 46(2), 209–244.

van der Velde, J. (1992). Technology in Basic Education. In Kananoja, T. (Ed.) *Technology Education Conference*. Helsinki: The National Board of Education (151–170).

Voyer, D., Voyer, S., & Bryden, M. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*(2), 250-270.

Ward, M. M. (2000). Robbing Peter to pay Paula. *Report Newsmagazine*, 26(52): 44–45.

Weber, K. & Custer, R. (2005). Gender-based Preferences toward Technology Education Content, Activities, and Instructional Methods, *Journal of Technology Education 16* (2), 55-71.

Wender, I. (2004.) Relation of Technology, Science, Self-Concept, Interest, and Gender. *Journal of Technology Studies 30 (3*), 43-51.

World Economic Forum (2015). *The Global Gender Gap Report 2015*. Geneva, Switzerland: World Economic Forum.

Yang, J, & Chen, S. (2010). Effects of gender differences and spatial abilities within a digital pentominoes game. *Computers & Education 55(3),* 1220-1233.

Book Review

Smith, C. (ed.) (2021). *Progressive Studio Pedagogy: Examples from Architecture and Allied Design Fields*. London and New York: Routledge. Contributors: Sean Burns, Magda Fourie-Malherbe, Gerhard Griesel, Charlie Smith, Andrew R. Tripp, Anika van Aswegen

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Anyone teaching in the field of architecture, landscape architecture and/or interior architecture and design will be familiar with the two staples of studio teaching: the so-called 'crit' or review (which may be formative or summative), and the tutorial (which may be done on an individual basis or in small groups, depending on numbers and resources). Whilst these two modes of teaching have their uses and have proven their efficacy (in replicating aspects of the professional environment students go on to work in, for example), nobody will deny there are challenges facing both the profession and design education today that require us to broaden our repertoire and consider – indeed create – ways and means to address current issues around employability, (in)equality, inclusivity and (academic) literacy. Increasing student numbers and continuing pressure on staff and resources have meant that educators have had to become ever more resourceful in maintaining quality and standards in design education. This makes *Progressive Studio Practice: Examples from Architecture and Allied Design Fields* (2020), edited by Charlie Smith, a particularly welcome addition to the field, as it addresses many of these issues through a discussion of concrete case studies drawn from architecture, landscape and interior design.

The authors are all experts in their field and demonstrate a thorough grasp of the literature relevant to the methods and strategies they propose. The chapters are thematically organised to reflect different aspects and stages of the learning process. Chapter One seeks to theoretically frame design learning as consisting of a 'composite of skill sets' that includes verbalisation and other communication skills alongside the predominantly visual or 'graphic' skill sets familiar from design practice. The authors here argue that a more holistic understanding of the skills required in practice will promote a self-reflective attitude and help design students, particularly those from disadvantaged backgrounds, to cope more effectively with the transition to higher education at the start of their studies. Chapter Two discusses some of the benefits that might be had from integrating writing in studio-based learning. Whilst some might consider such a move controversial, it is clear from the evidence presented that small writing tasks, especially where these are not assessed, can both facilitate and bring focus to students' learning and, more importantly perhaps, make writing less daunting and more versatile as an academic tool. Chapter Three considers the effect of disrupting conventional design learning by moving away from the traditional object-oriented approach to one focused on the user's perspective. It is argued that this change of viewpoint during the design process can bring about a 'transformative shift' in students' understanding of contexts and highlight the value of a more human-centred approach. Chapter Four is concerned with developing students' understanding of site and ground as inherently malleable and in dialogue with the design of architectural objects. Although the object-oriented approach is not fully abandoned here, or with some apparent difficulty, it is clear that students benefit from a more 'collaborative' thinking that sees the built object and the contextual surroundings as interrelated elements within the design process. Finally, Chapter Five discusses the benefits of peer review and the use of exemplars in helping students to make evaluative judgements about the quality of their work. It is argued that through such opportunities to critique each other's work, students gain a better understanding of how tutors review their work, whilst examplars also make it possible for students to gain an insight into the assessment process, even if the criteria are not always clear to them. Demystifying assessment remains an important issue in design education and so the value of student involvement and participation can probably not be emphasised enough.

The message that each of the chapters conveys is summed up well in the point made by Howard Gardner, quoted in Chapter One, which states that 'If you want to teach something that's important, there's more than one way to teach it'. And if one thing stands out from this book, it is the renewed importance of diversifying teaching methods so that students can learn in a multitude of 'multimodal' ways, each of which can contribute in their own modest way to making students the creative and critical thinkers and designers we want them to be.

Inevitably, a book comprising chapters by different authors will display a variety – indeed a kaleidoscope – of writing styles, some of which make for more enjoyable reading than others; in particular Tripp's more essayistic style in Chapter Two offers an engaging plea for the role writing might play in design education. There are moments when the book, being a work of pedagogical scholarship, can get a little dry and become jargon-heavy. I found some of the subheadings in Chapter One, such as 'Design knowledge semiotic process', 'Design skill set modal agencies' and terms like 'self-efficacy' to complicate the discourse unnecessarily and difficult to understand. The referencing (of secondary literature) can also at times feel slightly excessive, particularly in the last chapter. As Tripp's contribution shows, it is, and must be, possible for pedagogical research to present ideas without sacrificing readability for scholarly credibility, and one would expect an editor to bear their audience in mind and stress the need for simplicity in the use of language as well.

In terms of scope, the book cannot aim to exhaust the topic, though I wish the book had included a few more case studies to offer additional examples for educators to draw on, adapt or employ in their teaching, especially from outside the Anglo-Saxon context. It will be noted, however, that more recent editions in the Routledge Focus on Design Pedagogy series, of which this book is part, provide further examples of how to shape and enrich students' learning with a view to better prepare them for a rapidly changing world.

I should, finally, also like to offer a critical note with regard to the claim to innovation and the 'breaking of new ground' that this book makes. Innovation, in the current academic climate, is, like so much else today, prone to inflation and can easily ring hollow when pursued or invoked for its own sake. What may be considered innovative, or indeed 'progressive', remains, in the absence of a clear definition and related criteria, not only debatable (both in pedagogical terms and in view of the pressure on staff to produce original research), but also problematic, for there is also an argument to be made for tried-and-tested methods, some of which may have gone out of fashion or have been forgotten or have been in use for some time already (including peer review and working with exemplars), to be considered equally important and valid in attempting to 'nurture the enculturation of students into a community of practice' and, I would add, prepare them for careers outside of the profession. We know that a significant number of architecture and design students do not end up working in architectural or design practice and instead redefine their career along different trajectories and in other fields of study. For them, as much as for those who do become architects and designers, the teaching and learning environment needs to be able to accommodate strategies that are inclusive (of alternative methods) also from this, or indeed *their*, perspective. With this comment I hope to open and extend the debate around studio pedagogy with a view to making this learning and teaching environment perhaps less insular, inward-facing and self-centred than it often is. New ground can arguably best be broken by venturing into new territory beyond the confines of a discipline or involve other communities and practices than the one(s) we find ourselves working in.