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Editorial
From *flygskam* to *Zoomskam*

Lyndon Buck, Aston University, UK
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Welcome to issue 25.3 of the DATE journal. The final production and editorial writing of this issue coincides with the end of British Summer Time (BST) here in the UK, and as such it gives us a good excuse to pause and reflect on the last six months since BST began at the end of March. Dealing with change, embracing possibilities and working with ambiguity are things that we try to instil in all of our learners, so we should be good at this too, right? At this September's Engineering and Product Design Education Conference (E&PDE2020), virtually held by VIA Design, VIA University College, Herning, Denmark, it was both exciting and reassuring to see the variety and ingenuity that has been applied by learners and teachers in order to overcome barriers, both real and perceived, to the delivery and participation of educational activities. Many of the papers had been written before or at the early stage of national lockdowns and the 100 or so presentations were delivered remotely across more than 10 time zones, and it was fascinating to see authors reflecting on how their recent experiences had helped to shape their practice. The overwhelming feeling at the conference summary at the end of the second day was one of positivity, optimism, of looking forward with confidence, although we did all miss the conference meal. The lack of social interaction and meetings friends and colleagues in person was partly made up for by the lack of flight shame – *flygskam* – that so often accompanies an overseas conference visit. Perhaps one day we'll all develop Zoom or Skype shame? Whatever our feelings towards the technology, after two very full days in front of a computer screen it's fair to say that we all very much look forward to hopefully visiting Herning in person early next September for E&PDE2021.

Many of the E&PDE delegates suggested how we should and could develop the 21st century learning skills of critical thinking, creativity, collaboration and communication with a generic life skill of confidence or resilience, the ability to embrace change through flexibility, initiative and social skills. Having educational establishments with "invisible walls" is a long held aspiration for many and it may be that the events of this summer with hasten the positive moves towards removing barriers to educational opportunities and level the playing field for many. It was encouraging that in September the UK Engineering Council announced the newly updated 2020 edition of the Accreditation of Higher Education Programmes (AHEP4) document https://www.engc.org.uk/standards-guidance/standards/accreditation-of-higher-education-programmes-ahep/fourth-edition-to-be-implemented-by-31-december-2021/ and while there are many significant changes, the two new learning outcomes are significant. Firstly, graduates of accredited engineering or product design programmes need to consider the security implications of their practice, particularly around information and cyber security. Secondly, graduates must consider the importance of equality, diversity and inclusion (EDI), their personal responsibilities in this regard, and the benefits to individuals, employers and society more broadly. As these changes have to be implemented before the end of 2021 this welcome change should encourage and support new EDI initiatives over the coming year. Author

diversity, or a lack of it, is discussed further in the second book review in this issue by Liam Anderson and Alison Hardy.

Before we turn to the articles in this issue, we would like to pay tribute to Professor Jacques Ginestie of Aix-Marseille University, who sadly passed away in September. Jacques was Director of Ecole Superieure du Professorat et de l ' Education at AMU and one of the leading teachers, academics and researchers, nationally and internationally, of Technology Education. He committed his professional working life to increasing understanding of learning and teaching in science, technology and design in schools and in vocational education and was one of the most respected academics in our field. Kay had the pleasure of visiting him and his group of research students in Marseille on several occasions, presenting and sharing research with them and having the privilege to examine two excellent Doctorate theses of his students. A gentle, generous and kind man, full of French 'bonhomie', always welcoming with a smile, his quiet contributions to discussions with international colleagues always bringing understanding and insight, provoking reflection and thought, even when he might be explaining that to really understand the French philosophers, we must read their words in French! His contribution has been tremendous. He will be very much missed.

And now to this new issue of the journal, its 6 research articles, and 2 book reviews.

The first article is actually part of the primary special collection that was published in Issue 25.2 in June 2020 and that, for unavoidable reasons, was not able to be published in June. We are delighted that we can now publish it and it complements very much the collection of articles focusing on earlier stages of design and technology education. Remke Klapwijk and Niels van den Burg (Delft University of Technology, The Netherlands) present a case study research article *Involving students in sharing and clarifying learning intentions related to 21st century skills in primary design and technology education*. The case study is drawn from their research and development work on formative assessment of design skills: *Make Design Learning Visible*. The project aligns design skills with 21st Century skills and in this case study the focus is on their skill of "think in all directions" – divergent thinking. In a highly detailed study of a teacher working with 11 and 12 year old, the article provides insight into how the teacher used an interactive approach of brainstorming, interlaced with visualizing divergent thinking through making drawings and collective formative reflection, whilst designing. The case study provides valuable insight into the teacher's pedagogic approach and the thoughtfulness and critique this generated in the young learners.

The following five research articles come from different national contexts and phases of education that spread from primary education to postgraduate. Despite these differences the articles have several interesting recurring threads that run through: the importance of creativity, making and materiality, and especially the role of hands on experience in shaping our practice. Taken together they provide a fascinating example of what can be learnt through design and technology education at any educational phase.

In *Development of teacher education students' pedagogical content knowledge (PCK) through reflection and a learning-by-doing approach in craft and technology education* Sonja Niiranen (Tampere University, Finland), Pasi Ikonen, Timo Rissanen and Aki Rasinen (University of Jyväskylä, Finland) highlight the importance of learning by doing and making in Finnish craft and

technology education. The paper describes a study of teacher education students at University of Jyväskylä and their development of pedagogical content knowledge (PCK) through reflective and hands-on problem-solving sessions. Using a reflective questionnaire to further understand the outcomes of the 10 compulsory practical sessions in the syllabus, the authors found a collaborative approach to problem-based learning that in turn facilitates improved knowledge transfer, thinking and designing skills. In conclusion, the study suggests that this type of structured hands-on learning activity encourages teacher and peer interaction and in turn helps teacher education students develop their core PCK in craft and technology education.

In *A Toolkit for Practice-Based Learning of Mechanisms in Industrial Design Education: An Application of a Method Combining Deductive and Inductive Learning*, H. Güçlü Yavuzcan (Gazi University, Turkey) and Barış Gür (Venn Design Ltd, Turkey) explore how students on practice based courses develop their mechanical design skills by using a combination of deductive and inductive approaches. The authors discuss the controversies surrounding the perceived lack of industry ready industrial design graduates with the relevant mechanical engineering skills that employers require, which may be due to a misunderstanding of the core competencies of industrial designers, a subject still mainly taught as a crafts-based discipline. Through a focus on the industrial department at Gazi University, a toolkit has been developed to explore ways that design students can develop and apply their engineering knowledge in a more compelling way by combining a semi-deductive pre-assignment with a semi-inductive assignment. It is hoped that this toolkit will increase the efficacy of the delivery of technical theory and provide a controlled transition to experiential learning. The findings suggest that there has been considerable success in the application of the toolkit and it has allowed and encouraged a smoother transition from theoretical to experiential approaches.

In *Tracing back materialized ideas to embodied and verbal dialogues: Analyzing documents and videofootage of crafts and design lessons*, Verena Huber Nievergelt (Pädagogische Hochschule Bern, Switzerland) discusses the use of video and document analysis of ideation sessions for 9-10 year old primary age school children. Analysing how children interact with materials and their use of verbal and visual signals while engaged with a practical class, the author shows the results of the activity and characterises the design ideas. The use of video allows an analysis of the time spend on each stage and the effect of teacher interaction on these design phases. The research has culminated in the development of an e-portal for teacher education which although complex and challenging to create, could be a very useful resource for others working in primary level design and technology education.

In *Necessity of using Problem Based Learning (PBL) and Structural Physical Models on an Educating Structural Course: Case Study of a Structural Systems Course, Master Degree Architecture Students*, Ladan Vojdanzade and Katayoun Taghizade (University of Tehran, Iran) explore the problems arising from teaching structure and structural behaviour to architecture students. By using Problem Based Learning (BLM) and physical models and changing from theoretical to workshop and applied practical classes where behaviour can be learned without the reliance on complex theoretical mathematics. This approach, while requiring collaborative group work, also encourages reflection and an active learning role. This is seen as particularly important in architecture with it's reliance on the CPD continuous learning model for professional accreditation. In conclusion the authors suggest that making physical models and full size structures to study the fundamentals of structural behaviour is a more effective

solution to understanding the consequences of design decisions than previous course which relied on complex mathematical analysis. The hand-on approach also developed team working, collaboration and communication skills, and an active approach to their learning.

In *The Role of Spatial Ability on Architecture Education*, Saliha Türkmenoğlu Berkan, Saniye Karaman Öztaş, Fatma İlknur Kara and Ayşegül Engin Vardar (Gebze Technical University, Turkey) discuss the importance of spatial ability for architects and engineers, and how this skills can be developed through 2D and 3D representations and models. Through a series of spatial visualisation, spatial perception and spatial orientation tests, they evaluate students before and after a first semester architecture course, highlighting areas of further development that are required. By breaking down the existing elements of the course into the teaching activities, methods of presenting and skills developed, the study suggests the most effective methods of developing spatial skills, as well as discussing how these can and have often been developed in students before they arrive at university. The authors acknowledge that there is some further developmental work needed on the course, and they are hoping to enrol additional first year students from other architectural programmes into the study.

Finally, this issue includes two book reviews. Firstly a review of a recent edited book published by Intellect Books – *Re: Research, Volume 1: Teaching and Learning Design*. One of seven thematic volumes, this curated collection of papers from the proceedings from the 2017 International Association of Societies of Design Research conference, edited by Gjoko Muratovski and Craig Vogel is reviewed by Sri-Kartini Leet (Buckinghamshire New University, UK). In her introduction, Kartini highlights the range and scope of the papers and the commonalities that run through this collection. She provides a descriptive overview of each of the 11 papers, concluding her review with a critique which highlights what she sees as both strengths and weaknesses and an overall conclusion of the books value and contribution to teaching and learning design.

The second book review is of a recent edited book published by Springer Nature – *Pedagogy for Technology Education in Secondary Schools: Research Informed Perspectives for Classroom Teachers*, edited by P. John Williams and David Barlex, and reviewed by Liam Anderson (Trinity School, Newbury, UK) and Alison Hardy (Nottingham Trent University, UK). In their introduction the reviewers discuss their approach to selecting which 3 of the 16 chapters they chose to focus on and what is of particular interest within these for teachers of design and technology and STEM subjects. The review also discusses the high price of the book, which may put it beyond the reach of many potential readers, and also the lack of diversity of the 24 authors featured in the book. To conclude, the reviewers evaluate the overall accessibility of the book to the reader and its contribution to the discussion around accepted practice in the classroom.

We hope that you enjoy this issue.

Involving students in sharing and clarifying learning intentions related to 21st century skills in primary design and technology education

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Abstract
Design and Technology Education is an excellent vehicle for the development of the so-called 21st-Century skills, such as creativity, critical thinking and cooperation. However, the development of these skills through design projects does not yet reach its full potential. Formative assessment is able to support the learning of 21st-Century skills. In a case study a teacher shares and clarifies the goal of divergent thinking with her class of 11- and 12-year old's using a newly developed interactive approach. Small drawings were made collectively to visualize the skill. Half-way during the brainstorm session, students were asked to assess their brainstorm results and divergent thinking skills in a collective reflection. The results show that the interactive visual approach led students to understand how to be successful in divergent thinking. They collectively developed expressions to talk about how sound divergent thinking looks and this enabled them to diagnose strengths and weaknesses in divergent thinking. All interviewed students reported an improvement in divergent thinking after the collective reflection. This indicates that active involvement of students in clarifying learning intentions enables the development of relevant feedback. Although this result was only achieved in one class with one particular teacher, it underlines the value of the interactive visualization tool. Furthermore, it shows that the formative assessment strategy of sharing, clarifying and understanding learning intentions and success criteria related to 21st century skills in the context of real-life design projects supports self-evaluation and feedback uptake.

Keywords
Sharing and clarifying learning intentions, formative assessment, divergent thinking, primary education, brainstorming, self-evaluation

Introduction
Combined with the growing need for creativity in many occupations, policymakers, companies, educators and parents find it important that education cultivates creativity. Design and Technology activities are an excellent vehicle to develop creativity (Barlex, 2007; Klapwijk, 2017; Benson, 2017). Through an iterative design process, students learn to develop original and relevant solutions.

However, although design activities have the potential to stimulate learners to develop creativity and other 21st century divergent thinking skills, this potential is often not achieved. Schut, Klapwijk, Gielen, Van Doorn and De Vries (2019) observed design fixation among primary

school pupils, while Lindfors, Heinola and Kolha (2018) concluded that avoidance oriented students tend to avoid developing solutions during a design challenge.

Formative assessment could support the learning process during design projects as it is meant to directly influence the learning process. It is defined as "*any assessment for which the first priority in its design and practice is to serve the purpose of promoting students' learning*" (Black, Harrison, Lee, Marshall, & Wiliam, 2004, p. 10). Important is "*the process of seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning, where they need to go and how best to get there*" (Broadfoot, Daugherty, Gardner, Harlen, James, 2002, pp. 2-3). Formative assessment has profound learning gains especially when teachers include strategies for sharing, clarifying and understanding learning intentions and success criteria (Wiliam 2018; White & Frederiksen,1998).

Five key-strategies for formative assessment should be used in an integrated way (Wiliam, 2018):

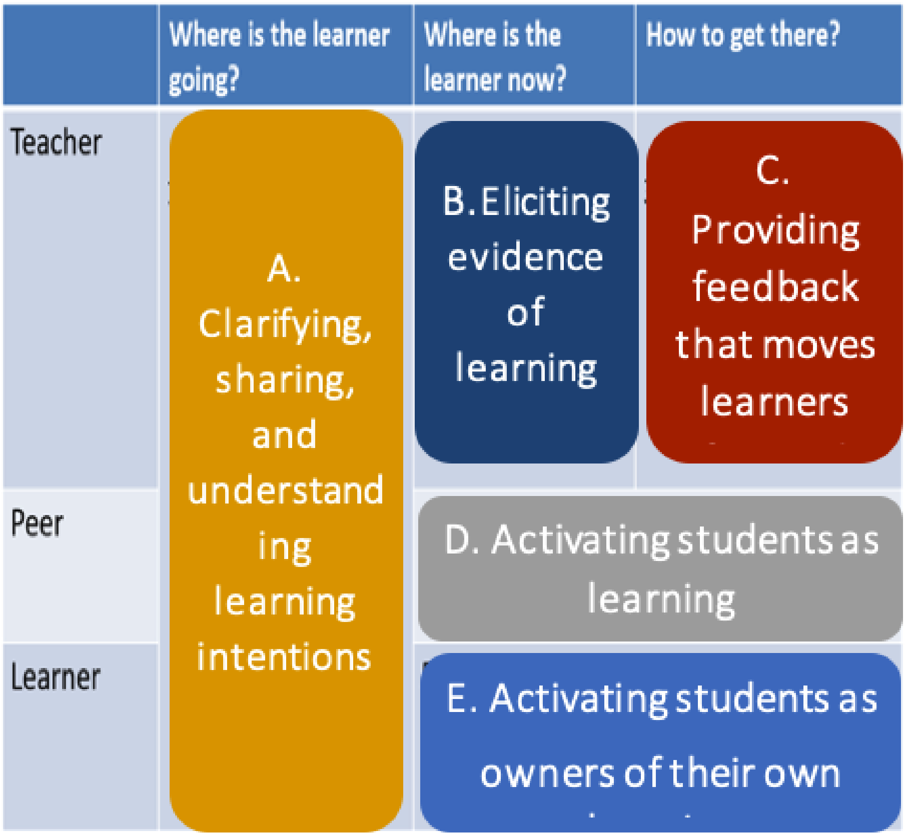


Figure 1. Five key-strategies for formative assessment (Wiliam 2018).

In the context of authentic design and technology projects, many of these formative assessment strategies have been developed. To elicit the unpickled design process (strategy B), e-portfolios affording multi-modal responses (text, drawing, photo, audio) have been used. Initially, these e-portfolios were used for summative assessment, but soon the rich evidence was applied formatively enabling teachers, students and peers to reflect on the design process and (intermediate) outcomes leading to timely feedback (strategy C and D) (Davies, Collier, & Howe, 2012). Peer feedback was also central in Adaptive Comparative judgement (ACJ)

approaches in which students compare design outcomes one by one in an holistic way (Bartholomew, Strimel, Yoshikawa, 2019; Seery, Buckley, & Delahunty, 2019). As a result of providing peer feedback, students developed a nose for quality and were better able to judge their own design outcomes (Seery et al. 2019). Various formative assessment studies have focused on supporting teachers in eliciting evidence through thought-provoking questions that help students to assess the value of their designs and to organize their design processes (Stables, Kimbell, Wheeler & Derrick, 2016; Swathi, Fox-Turnbull, Earl-Rinehart, & Calder, 2020).

However, in none of the formative assessment studies found in the domain of primary and secondary design and technology projects, learning intentions and success criteria have been explicated beforehand to the students. In most approaches, students discover the learning intentions only during the design practice. Compton and Harwood's (2003) framework is a positive exception and the described case-studies include sharing specified learning goals beforehand. However, no specific tools were used to achieve a better understanding. As a result, students usually embark on design journeys without a clear vision of the learning intentions.

In design and technology projects, many learning intentions are possible due to the 'whole task approach' ranging from scientific and technological principles, design skills such as creativity as well as practical make skills (McLaren, 2007). This is due to the whole task approach, but the complexity of learning to design may easily overwhelm primary school students and this hinders learning (Looijenga, Klapwijk & De Vries, 2015). A similar problem is noticed in higher design education (Van Dooren, Boshuizen, Van Merriënboer, Asselbergs, & Van Dorst, 2020). Students are just practicing design without learning to design because design skills and certain ways to move through the design process are not clarified. Van Dooren et. al. developed an approach to explain central features of the design process that need to be learned.

In primary schools, formative assessment strategies focusing on sharing, clarifying and understanding learning intentions in the context of real-life design and technology projects are needed. At the Delft University of Technology, a formative approach called "Make Design Learning Visible" was developed, including four tools for clarifying, sharing and understanding design skills (strategy A in figure 1). A case-study was conducted and used to explore how a primary school teacher used an interactive visualization tool to create a dialogue on the learning intentions and success criteria related to divergent thinking in a class with 10 to 12 year old's. Next, students practiced divergent thinking during a brainstorm followed by class discussions in which they reflected on divergent thinking and were given the opportunity to apply the feedback in a second brainstorm round.

The main research question is: *Which factors contributed to successful clarifying and sharing of the learning intention of divergent thinking and under which conditions does this support students in assessing and changing their divergent thinking behaviour?"*

The outline of this paper is as follows. In the next section, the benefits of sharing, clarifying and understanding learning intentions in design and technology projects is described. Following this is a section that explains the decisions made in the development of "Make Design Learning Visible" approach and how learning intentions related to 21st century skills have been formulated. The research methodology is then described, followed by results and conclusions.

The value of sharing, clarifying and understanding learning intentions

Many researchers consider clarifying and sharing learning intentions and success criteria foundational to formative assessment (Wiliam, 2018; Gulikers & Baartman, 2017; Wylie & Lyon, 2015). Empirical studies indicate that teachers who do well in clarifying learning goals, are also more effective in the subsequent stages of the formative assessment cycle (Gulikers & Baartman, 2017).

Sharing, clarifying and understanding learning intentions is important for the formative assessment process as a whole and influences the four other strategies. Students are not automatically on the same page as their teachers and may have different ideas about what they are learning, or they have no clue at all as Gulikers & Baartman (2017) conclude in a meta-analysis referring especially to four studies (Bloxham & Campbell, 2010; De Lisle 2015; Hogan, Towndrow & Koh 2009; Newby & Winterbottom 2011). Explicating learning intentions will raise the participation of students in the formative assessment process as clear intentions enable them to monitor their own work as well as to assess the work of their peers (White & Frederiksen, 1998). Students can learn more independently once they know the success criteria in a tangible way. They are able to practice design and learn from it without direct support as self-correction is possible. This also stimulates ownership of learning.

Research shows that around 50% of the learn- and feedback activities of teachers are not related to the learning goals (Moss, Brookhart & Long 2013). Explicating learning intentions and success criteria beforehand provides a focus for eliciting evidence and feedback. In real-life tasks such as design and technology projects, understanding the learning goals might even be of greater importance as learners may become easily overwhelmed by the amount and complexity of possible learning intentions (Looijenga, Klapwijk & De Vries 2017; Van Dooren et al. 2020). This is due to cognitive overload when performing real-life tasks without substantive support (Van Merriënboer & Kirschner 2018).

McLaren (2007) also states that clarity is needed on the learning intentions and indicators of progression and advocates multi-dimension assessment in design and technology education. Teachers – especially those in primary and secondary education who are usually not designers - need to know what to look for when they formatively assess. In Dutch primary classrooms we experienced that assessment tends to focus on cooperation and communication, and not on any of the other 21st century skills. A similar problem is prevalent in peer assessment practices in a design project described by Bartholomew, Strimel and Yoshikawa (2019). Here, secondary students tend to comment mainly on the appearance of the designed posters and hardly on other qualities such as empathy or creativity. All parties involved in design and technology projects, need to understand what the learning intentions are and how quality looks before they practice and assess design learning.

"Make Design Learning Visible"

The Delft University of Technology and its partners developed the "Make Design Learning Visible" approach (Klapwijk, Kok, Visschedijk, & Holla, 2017; Klapwijk, Holla, & Stables, 2019) that aims at formative assessment of design skills.

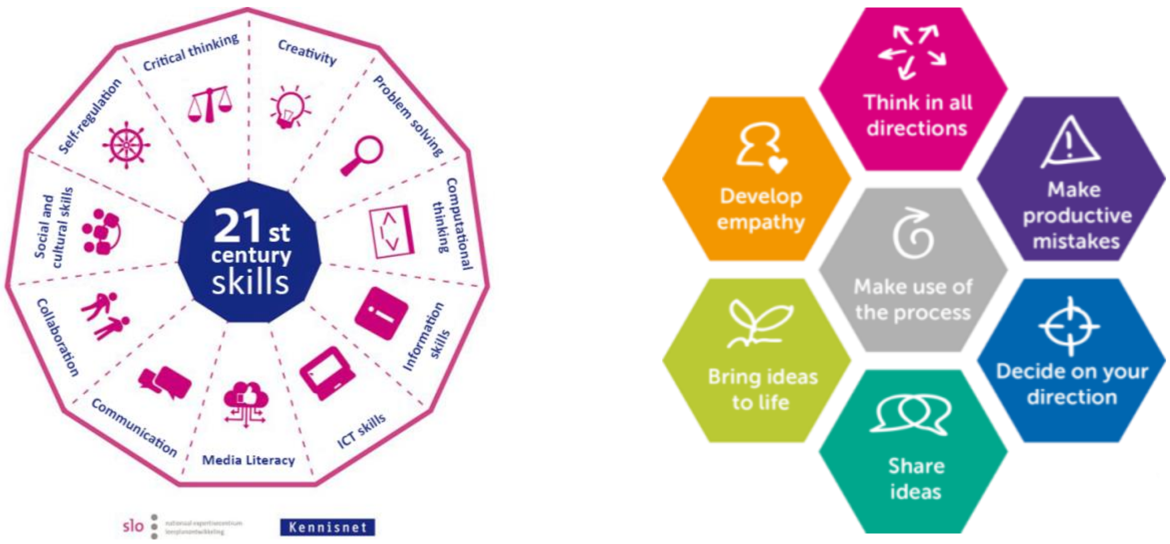
Formative assessment experts in design and technology education have advocated a process-based approach instead of a product-based approach (Kimbell 1997; Fox-Turnbull, 2006) as the process reveals more about the learning process. However, case-studies on these process-based formative assessment approaches show that feedback tends to focus on what steps to take next in the design process (Kimbell, 2012; Swathi et al. 2020).

We therefore choose to focus our approach on 21st century skills, these are generally associated with higher order skills and behaviours that represent the ability to cope with complex problems (Voogt, & Pareja Roblin, 2012), see the example in figure 2. Although 21st century skills are not the only goal, they are at the core of what students should learn from designing. Each skill would invite teachers and students to look with a specific angle to the design process and its outcomes. Aspects for assessment are isolated while practicing the whole task, e.g. distinguish between the quality of creative thinking, cooperation or information seeking.

We assumed that assessment of 21st century skills enables focussing on the learning process because isolating specific skills in a complex design process will stimulate the kind of diagnosis and specific feedback that moves the learner forward. This approach in formative assessment is relatively new in the context of design and technology projects but similar to the one Frederiksen and White (1998) applied in the context of inquiry based learning. They focused assessment on a limited number of research skills, introduced these two at the time and students are asked to reflect on them after each research task. This was highly beneficial for the development of these research skills and knowledge growth accelerated as well, in comparison to the control group, especially for students who had low scores in literacy and numeracy.

In developing the descriptions of the skills, we had to balance between being too general and being too specific (Aschbacher & Alonzo, 2006; Torrance 2007). When a learning intention is too specific and includes the context, it cannot be transferred to other situations (Clarke 2005; Wiliam 2018). Teachers often make the mistake of sharing learning intentions in a contextualised way, for example, students are told that they need to be able to analyse a questionnaire about movie-going habits. However, the real learning intention is that students can analyse questionnaires on any topic. Therefore learning orientations have to be formulated in a context-free way.

21st century skills are context-free; however we judged that they would be too broad for self-monitoring. We therefore decided to translate the 21st century skills to more concrete design skills. To help teachers and students, an overview is needed which is relatively simple to remember and easy to use. This resulted in seven key design skills (Klapwijk, Kok, Visschedijk, & Holla, 2017; Klapwijk, Holla, & Stables, 2019) (see figure 1 and Appendix 1). Although these seven design skills are in line with the literature design, they could have been selected differently.



21st century skill	Design skill
Creativity Problem solving	Think in all directions Bring ideas to life Make productive mistakes
Communication Collaboration	Share ideas
Social and cultural skills	Develop empathy
Self-regulation	Make use of the process
Critical thinking Information skills	Decide on your direction
Computational thinking ICT skills Media Literacy	Depending on the theme

Figure 2. Relating design skills to 21st century skills of the Stichting Leerplan Ontwikkeling (SLO) and Kennisnet model

In figure 2 the design skills are related to 21st century skills formulated by the Dutch curriculum organization SLO. Creativity is quite a catch-as-catch-can concept and is too general for guiding assessment. The hexagon model therefore divides creativity into: 1) thinking in all directions (divergent thinking), 2) making ideas tangible (converging thinking) and 3) making productive mistakes. In creative processes, two cognitive processes are important, divergent and convergent thinking (Howard-Jones 2002; Goldsmidt, 2014). Divergent thinking is generative in nature and entails the generation of new thoughts, ideas and perspectives, while convergent thinking is evaluative in nature and entails reflection of these thoughts, ideas and perspectives (Sowden, Pringle, & Gabora, 2015). In addition, as creativity is stimulated by experimenting and iterating (Looijenga et al. 2015), “make productive mistakes” was isolated as skill. Skills related to inquiry and research are also relevant for design, but a separate set was developed, these are not discussed in this article.

None of these design skills is tied to a specific stage in the design project. Each skill is important all over the design project. As such, they can be used to isolate elements of the design practice and lead to specific feedback. Evidence for the functioning of a skill can be derived from various sources: the process, the product, the person and it is also possible to collect information about the press that influences skill development. Press relates to everything surrounding the creative design process and ranges from school culture, design tools, teachers, peers to physical surroundings. This rich approach to evidence collection was inspired by the 4P-model of Rhodes and is described in detail for assessment of creativity in the International Handbook of Technology Education (Klapwijk, 2018).

Nineteen tools were developed to make all five strategies of formative assessment feasible (see Appendix 2). Four tools focus on clarifying, sharing and understanding design skills and success criteria;

1. *Practice your skills*: skill cards support students to understand design skills, see figure 3.
2. *Symbols for design learning*: design learning symbols such as or are used to show students which skill they are developing
3. *Evaluate examples in advance*: learners analyse and discuss examples of design projects to discover success criteria beforehand.
4. *Visualize a design skill*: students explore in images and text what you have to do when you apply a design skill successfully

Figure 3. Skill card explaining divergent thinking (Klapwijk et al., 2019)

Using examples before students embark on a new project is a well-known strategy in formative assessment, often applied in the context of language learning (Hawe & Dixon, 2014). At first

sight, it looks similar to ACJ, however, students discuss anonymous examples from another class and compare good and less good examples of a specific design skill.

As the tool "Visualize a design skill" is rather innovative and we wanted to know if it helped to clarify learning intentions and how it supported the other formative assessment strategies. Our research question is "*Which factors contributed to successful clarifying and sharing of the learning intention of divergent thinking and under which conditions does this support students in assessing and changing their divergent thinking behaviour?"*

Methodology

An explorative research design was applied because knowledge on using visualization to involve students in clarifying learning intentions is not available. A qualitative case-study was carried out to gain a first insight in the underlying mechanisms of the tool and develop suggestions about strategy A (figure 1) in design projects.

Participants

A Dutch school participated with a class of 11-12 year old's. The participating school is, 'development-focused', meaning that umbrella themes are used to integrate different learning subjects over the course of a few weeks. The students were accustomed to collaborate in teams over a longer timeframe on a range of educational activities. The class was divided in gender-mixed design teams of four students by the teacher. The teacher had been involved in an earlier research project on the same design project, however, it was her first time to facilitate a complete design project.

Design problem and sessions

The students were asked to design new activities for the gym of the future in a design approach based on the Creative Problem Solving model (Isaksen, Dorval, & Treffinger, 2010; Tassoul, 2009) in which divergent and convergent activities alternate. The educational approach has been described earlier in a study with different students (Schut, Klapwijk, Gielen, Van Doorn, De Vries, 2019). In six sessions (1.5 hour each), teams explored the design problem, generated solutions and elaborated these solutions (figure 4).

Formative assessment

The formative assessment focused on divergent thinking and two tools from the "Make Design Learning Visible" approach were used: Visualize Design Skills" and "On the right track?" "Visualize Design Skills" was used during session 1 for strategy A, students' suggestions on how to think divergently were collected and the class collectively devised symbols to depict the suggestions (figure 4).

Next, students practiced a brainstorm in session 2. During a second brainstorm in session 3, a teacher-led reflection on the process and products of divergent thinking so far was held. After this, another brainstorm round took place to enable students to apply feedback and newly developed insights on divergent thinking. Pausing halfway during an activity to reflect on a specific design skill is part of the toolbox and called "On the right track?" (strategy B and C).

Both tools were explained to the teacher by the second author and she received the toolbox (Klapwijk, et.al. 2017).

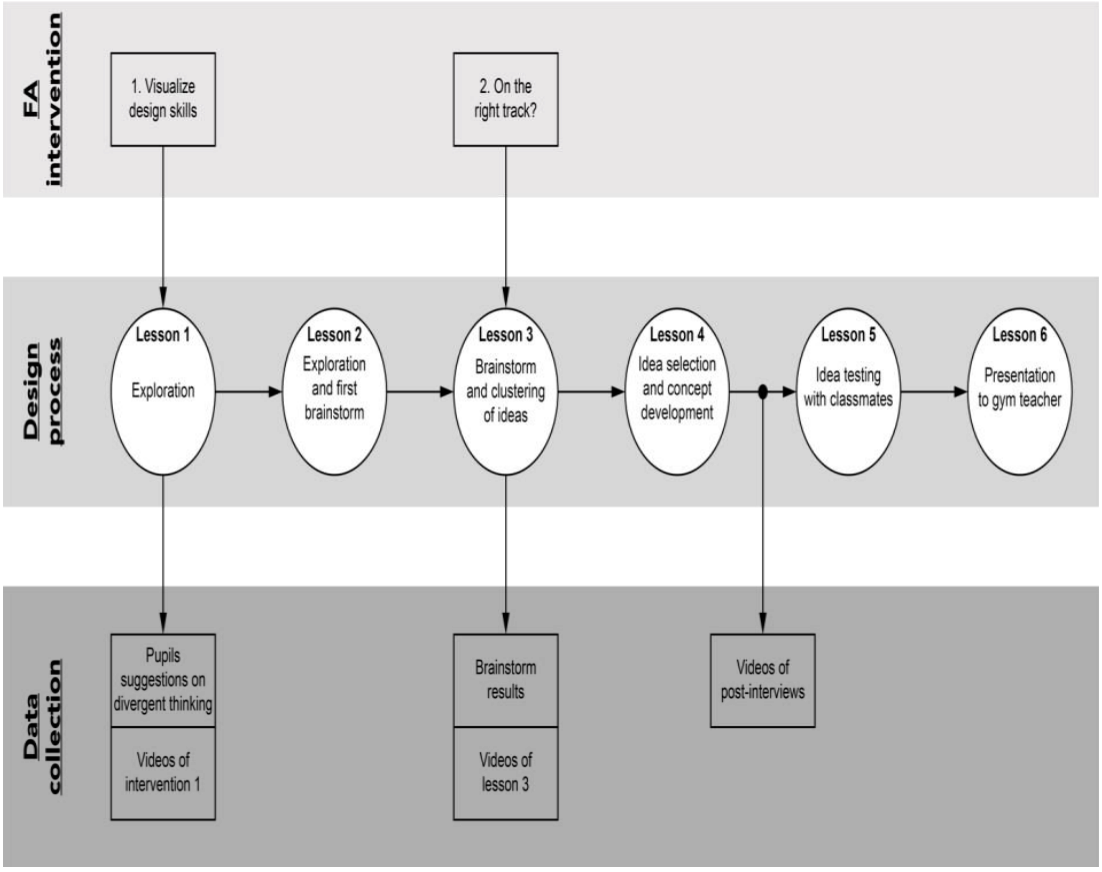


Figure 3. Formative assessment tools, design process and data collection.

Data collection

Audio- and video-recordings were made of the formative assessment activities in session 1 and 3 and transcribed. Two teams that were thought representative by the teacher were specifically followed. Both brainstorm sessions during session 3 were recorded. Fieldnotes were made by the second researcher.

Pair-wise post-interviews with 7 students from the selected teams (1 team member was sick) were conducted a week later focusing on the pupils' awareness of divergent thinking, their experiences during the teacher-led pause and their ability to assess and change their divergent thinking. The themes in these semi-structured interviews were: understanding success criteria in terms of products and processes of divergent thinking, ability to diagnosis and change own divergent thinking, compare outcomes of the two brainstorm rounds. Pre-determined questions were used for each theme, followed by free-following questions.

Specific episodes from the videos were shown to obtain an explanation from involved students about what was happening. The episodes were related to students showing signs of formative assessment, e.g. students trying to diagnosis their own thinking process or supporting peers in divergent thinking. Each pair received questions in free-flowing way.

Students' work was collected: the visualized learning goals (figure 5) and brainstorm results from session 3.

Data analysis

All audio- en video-recordings were transcribed. The data were first analysed by the second author and then by the first author. Guildford's definition of divergent quality (many, varied and original) was applied to assess understanding of and changes in divergent thinking (Guildford, 1967) . The class dialogues were analysed bottom-up using the research question as a guidepost. Indicators to analyse the self-reports were inspired by Guildford.

Results

This section describes the formative assessment interventions and their effect on divergent thinking. The results of the post-interviews are presented to clarify how students understood the goals and success criteria of divergent thinking and applied it to their own thinking processes during the brainstorm.

Visualize divergent thinking

At the start of the design project during session 1 the learning intention was visualized. On a smartboard, an empty matrix is shown and teacher Katy tells her class that they will generate design ideas for the gym of the future next week and asks "*What do we need to do when we think in different directions*?" Subsequently ten proposals are made by nine different students and transformed in eight icons, see figure 4. We selected a number of representative dialogues to show how the learning goal is clarified. Verbal utterances are often ungrammatical, this is also present in the English translation.

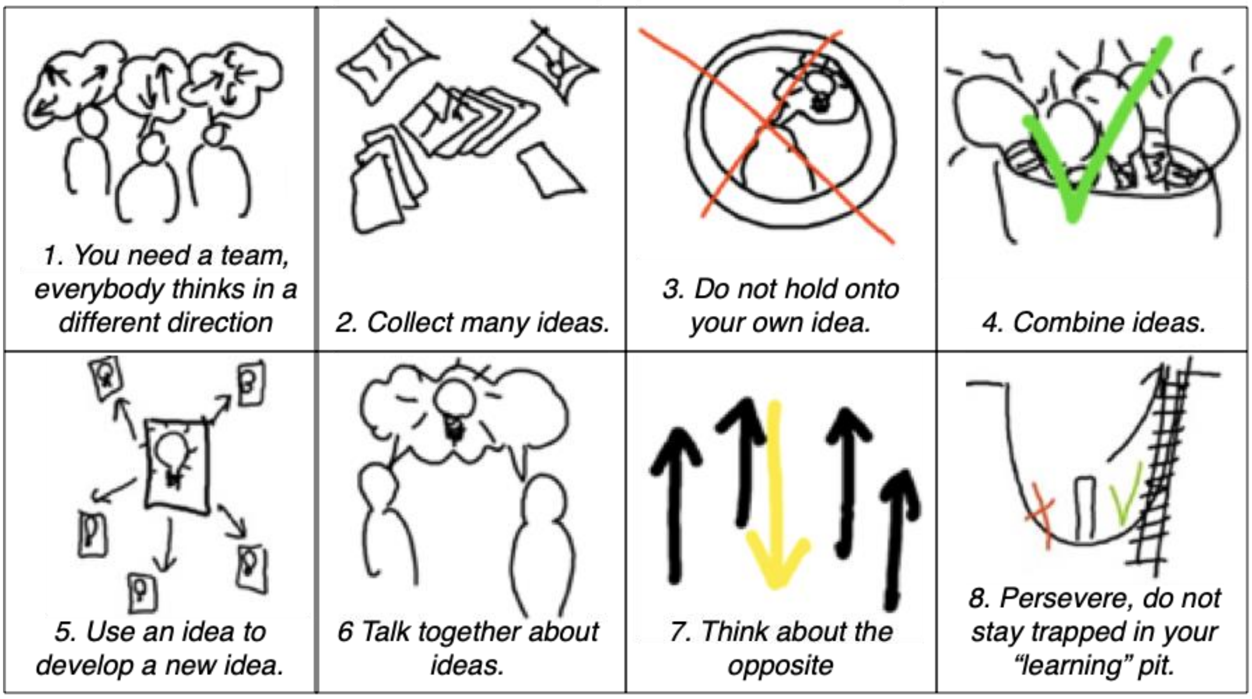


Figure 4. Icons

<u>P1. First proposal</u>

1. Teacher: “Think in all directions.”
2. Anna: “Yes.”
3. Teacher: “What do you have to do for this?
4. Anna: “You should just a little bit…. well…. how do you say this….eh you should think of what you want.”
5. Teacher: “Think of what you want?”
6. Anna: “Yes, well agree which each other. A little bit…”
7. Teacher: “Agree which each other. Are you still thinking in all directions? When you all have to agree?”
8. Anna nods vehemently no.
9. Teacher: No, not so much.
10. Teacher: “But it does help us, because you started hands are being raised over there. It is very good that you started.”

The teacher acts as a gate-keeper and Anna and the teacher decide that agreeing with each other does not belong to divergent thinking. A misconception is tackled. The teacher creates a safe environment by acknowledging the value of Anna’s contribution.

<u>P2. Second proposal (Icon 1)</u>

1. Evelyn: “Well, you all have just…… because when there are more people in your team, you will all have different ideas. As a result everybody will think in a different direction, something like that.”
2. Teacher”: “Well, for thinking in all directions you need to have more people involved. You need your team members. OK.”
3. Evelyn: “Yes, I think so.”
4. Teacher: “How can we…do we think that this is handy? Is Evelyn right when she says, when you are with more people, you will generate more ideas.”
5. (several students show in their behavior that they agree)
6. Teacher: “How can we show this in a little drawing…who has a small idea for this? That you need more people?”
7. Pupil 2: “A few little men.”
8. Teacher: “A few little men.”
9. Pupil 3: “About four of them.”
10. Ella: Yes! With little arrows above their head. (Suggestions by other students at the background, inaudible at the recordings)
11. Teacher: “A few little man…. and a cloud representing the idea. That is what you said. It (referring to her drawing) looks like a wood. With arrows…because they all think in different directions, is that what you meant Ella?”
12. Ella: “Yes.”
13. Pupil 4: “They all think in different directions.”
14. Teacher: “OK. There are more of them and they all think in a different direction.”

The teacher rephrases and checks the idea with Evelyn and the whole class, thus stimulating active involvement of everybody. The drawing of the advice evokes even more active participation, many students are involved in co-developing the picture.

<u>P4. Proposal 4 (Icon 3)</u>

1. Allard: “One person tells I want this and another that…and we say to each other OK we don’t bother we just do one of them. I mean, we should (instead) take my idea and mix it with Tom’s idea and then…”
2. Other pupil interrupts: “Throwing everything together
3. Teacher: “Oh…”
4. Allard: “And then a new answer will hatch and …”
5. Teacher: “You did some good thinking.”
6. Allard: “Mix everything.”
7. Teacher: “So, you say let’s share ideas to let something new originate. You are thinking, this is very handy, so you should not stick to your own idea. Actually you say two things, your own idea, we can maybe make a drawing of this, don’t stick to your own idea and bring all idea’s together, because good ideas can yield even better ideas.”
8. Teacher: “Let’s start with the first drawing, don’t hold on to your own idea, how can we draw this? Mary?”
9. Mary: A traffic sign with your own idea and next a cross, something like that.”
10. Teacher: “So.”
11. Mary: “So you will not only focus on your own idea”
12. Teacher: “Should it be a prohibition traffic sign?”
13. Mary: “Yes.”
14. (other voices at the background indicating agreement)
15. Teacher: “One person with an idea on the sign.”
16. Pupil 1: “Yes, a little man.”
17. Teacher: “OK.”
18. Pupil 2: “And a cloud of thinking with a traffic sign in it and next a cross.”
19. Teacher (*while drawing*): “Don’t hold on to, forbidden, this should be red, a little man*, plieng, plieng (making sounds)*, he doesn’t have a neck…with a light bulb*, tjup tjup tjoeps, plieng, (making sounds)*. So this is a prohibition traffic sign.”
20. Mary: “It needs a cross.”
21. Teacher: “It also needs a cross…a cross, to be clear.”
22. Pupil 3: “Red.”
23. Teacher: “Ready, don’t hold on to your own idea.”
24. Students are laughing.
25. Some-one (maybe contributor Allard): “And mix everything.” (Class continues to develop icon 4)

This dialogue shows that visualizing is engaging for students. The teacher invites everybody to suggest drawings, draws out loud, paraphrases and uses suggestions on the fly. Idea’s for drawings come mostly from students that were not the one coming up with the advice. When Allard suggests that one should not hold on to one’s own idea, Mary proposes to use a traffic sign. The use of drawings provides room for the teacher to repeat ideas (P4, line 19). The students develop their own vocabulary, “to mix everything” and the image of a “cooking pot” for randomly combining ideas (icon 4).

Other proposals follow and Katy takes time to elicit the idea. She either repeats the key-idea in exactly the same words of the contributor (P1, line 5), or she rephrases the idea in her own words (P4, line 7). She often checks with the contributor if she understands the idea right (P2, line 2). At one point, a girl has difficulties explaining her idea to the class. But the rephrasing by the teacher and the subsequent visualization proposals of her peers result in a shared understanding.

At the end of the activity, Lana voices a misconception as she confuses divergent and convergent thinking. The teacher helps her to understand the difference between the two.

P8. Proposal 8 (No icon)

1. Lana: "Maybe make one big idea with your team."
2. Teacher: "Have a quick look – what is the skill we are talking about? "
3. Lana: "Yes, OK. "
4. Teacher: "The current skill is about thinking of something good, we will start with exploring all the different alternatives, think in all directions…eventually the goal will be to develop one idea… but this is one step ahead. So, you should keep this idea in mind, however, the idea does not belong to thinking in all directions."
5. Lana shows that she agrees.

This dialogue led to the next proposal.

Proposal 9 (icon 7 Think about the opposite)

1. Thomas: You should try to think in a completely different direction
2. Teacher: A sort of the opposite
3. Thomas: Yes, you should…
4. Teacher: How can we…do you have a drawing in your head Thomas?
5. Thomas: arrows, they are all going in different directions
6. Teacher: So, when we make arrows, I am going to make them a little bit thicker. We all think a bit like this (drawing arrows in the same direction), we all have ideas in this direction, it would be fun if we turn one idea completely around. Think in a completely different direction for a moment. Excellent.

Visualization of the proposals pulls many students into the dialogue and co-development of the learning goal.

The way the teacher leads the dialogue creates a safe climate and involvement of many students. She repeats ideas in exactly the same words or rephrases idea's and keeps checking if she understood the students. She acts as a gatekeeper for misconceptions (P1, P8) and this evokes further clarification (P2, P9). She sometimes elaborates the idea, but students are the main developers of the advices for divergent thinking.

The developed icons contain much process-related advice (together, combine, do not hold on to your idea, think of the opposite, do not give up, collect many ideas). Also, the kind of outcomes one looks for become clear (many ideas, variety, new ideas resulting from combinations). Elements related to press are prevalent (with a team).

Brainstorm in two rounds using "On the right track?

Groups of four students work together in the design project and each of them had generated a specific design assignment within the theme of physical education. The teacher asked the students to brainstorm individually, write and draw their ideas on small sheets of paper. The first four minutes they came up with ideas were without any other support followed by ten minutes in which they used pictures pulled out randomly from a shared envelope. A few episodes were present in which students' diagnosis their own or peer brainstorm activities or provide feedback.

Lana is speaking out loud during her brainstorm. Lianne, from the same team, reacts:

1. *Lana: "I am continuously (thinking) about dodgeball."*
2. ………….(other comments)
3. *Lana: "Dodgeball, dodgeball, dodgeball."*
4. *Lianne: "Lana, empty your head for a minute, because you only think about dodgeball."*
5. *Lana: "What?"*
6. *Lianne: "You think only about dodgeball."*
7. *Lana: "Yes, yes, I know"*

Lianne realized Lana's fixation on dodgeball when she heard Lana speaking out loud to herself. She also noticed that Lana filled many idea-cards with dodgeball ideas. Lianne 's diagnosis and feedback helped Lana. In the post-interview, Lana reports that from this moment on she started to think in a different direction and changed her current picture for a new one.

Danique from the other videotaped group is able to diagnosis her own situation. When we show her video fragments of the first round, she explains that she, after a period of being absent minded, realized that she was not able to come up with ideas: "*Well, I didn't really understand the meaning of the picture. And I was not really able to connect an idea to it (the picture) …I was thinking about a rugby ball, but then I was thinking…. well, rugby in a gym is maybe not a very good idea*" Although Danique realizes that she was not able to write down her ideas, she was not able to adapt her approach.

On the right track?

The teacher pauses the brainstorm to have a class dialogue to diagnosis and assess the divergent thinking so far. She starts with a series of questions about the amount of ideas and the variety of ideas, applying Guildford's criteria. "I *have a question about thinking in different directions. Take some time to think about this. Did you (plural) come up with many ideas?"*

Many students react, and a loud 'yes' is audible. Next she asks the students about variation in ideas:

1. Teacher: "*Did you (singular) succeed in coming up with different ideas?"*
2. Denise: *"I first thought of a tag game, after that I came up with a ball game and then another ball game."*
3. Teacher: "*Can you explain why you succeeded? "*
4. Denise: *"Because of the images."*
5. Teacher: *"The images helped you this think in a different direction, a new kind of game."*
6. Lana: "*When you had a picture and did not know what to do, you could look at other pictures and I combined these*."
7. Teacher: "*Oh yes, I immediately get an icon in my head, from one idea to another."*

The probing question (line 3) and her paraphrasing (line 5, 7) help the students to elicit the processes that made them successful.

Later, another girl compares her brainstorm with and without pictures and explains that she had great difficulties in coming up with any ideas at the start of the brainstorm. This makes Joris

suddenly realize that he was fixated and says: *"Because I had been busy with the topic yesterday, I stayed stuck to this topic the first three minutes. I thought of a new idea that could go with it, but then, I kept holding on to what I did yesterday."*

Joris explains in the post interview: *"I realized this (the fixation) during the pause, because the teacher said something like "How did it go? And then I thought, I was too much engaged with my idea from yesterday."*

The teacher evokes more responses and asks: "W*ho recognizes this*?" Approximately half of the class holds up hands to indicate that they experienced the same problem. As such students became a learning source for each other (strategy D) and learned from each other's diagnosis (strategy B).

Usually, teacher Katy initiates a dialogue, but in the example below a student who worries about her brainstorm results, starts a dialogue.

1. *Danique; "I thought eh…because many children said that it should be games. I thought we did it wrong."*
2. *Teacher: "What was your design assignment?"*
3. *Class: "Oh…" (surprised).*
4. *Danique: "Eh…a game for physical education."*
5. *Other pupil: "For teams."*
6. *Another pupil: "Design a new game for physical education that helps to select a team."*
7. *Teacher: "Ok."*
8. *Danique: "Did we have to relate to it (the brainstorm to the question)?*
9. *Teacher nods.*
10. *Danique": "Some of our ideas match, I suppose."*
11. *Teacher: "Ok. So your approach was more broad than the design question. Maybe I should have made it more clear."*

Through the questioning of teacher Katy (line 2), Danique and a number of other students start to understand that the specific design assignment is important for the direction of the brainstorm.

Next, a summary of what went well and of things they could change is assembled. The class develops various advices to forward the divergent thinking process, e.g. a team mentions that they want to focus more on the design question. Danique, the girl who knew she was fixated during the brainstorm, suggests "Don't stick to your idea." The teacher gives one suggestion:

1. *Teacher: "I was walking past by one of the teams and they were writing their ideas down and I then told them that they were allowed to draw as well. The day before this was a question that was often posed: Should I write or should I draw. .….*
2. *Pupil: "I did both."*
3. *Teacher: "You just did both. That is fine. But when I passed someone who heard "I am allowed to draw as well", she went like a rocket and suddenly it was a lot easier to proceed. "*

The refection halfway through the design activity was based on the tool "On the right track?" and enabled students to collectively elicit and diagnose divergent thinking. They identified the

power of the using pictures as well as the occurrence of fixation. The icons and the criteria of many and varied formed a reference point. Also, a new success criteria was discovered, you need to generate ideas that relate to the design question. After this, a second round of brainstorming of 10 minutes was organized using random pictures as inspiration source.

Self-reports on divergent thinking

Below the results of the post-interviews are given.

Insight in outcomes of divergent thinking

All seven interviewed students have captured the idea that one needs to think of many ideas.

Danique:	"Yes, Yes, you have to …. Ok, not hold on to your own idea and …you should not one, but generate many ideas."
Interviewer:	"How many?"
Danique:	"As many as possible."
Interviewer:	"OK, not hold on to your own idea. Generate as many ideas as possible. Anything else?"
Danique:	"Ehm.."
Interviewer:	"What did you mean with "Don't hold on to your own idea'? "
Danique:	"Well, eh…also…you have to be open for ideas for other people. And not just perceive only your own idea as being good. "

The post-interviews show that they all understand having varied ideas is important. For example, a pupil explains that she had first an idea with a ball game and next an idea about dancing, or first an idea for a small group of players and then an idea for a big group. They also know that divergent thinking is about having new ideas. Most students use the term new in the sense of an idea that they as a person or group did not have the idea before.

The idea combining elements in a new way is relevant, is also known to the seven students and they applied this strategy:

Joris:	"We had also ideas with handball and soccer and we developed a sort of …."
Livia:	"Yes, and then …soccer without hands, so you also…."
Joris:	"You may use your hands when you are not able to go on, when you are completely locked in, then you can take the ball into your hands and you are allowed to throw it away."

This shows that students understand most of Guildford's criteria of divergent thinking outcomes. However, the idea of having unusual or original ideas was only clear for two students. Denise and Sophie mention this, e.g. "*It should be something that is totally different. For example a piano lowered in the floor, sponges a person can tumble on or a very strange dance battle with a flashlight in the gym*."

The students were able to explain the kind of processes needed for divergent thinking. Quite often, they used expressions from the collective drawings or reflection, e.g. "you should not stick to your own idea" (Danique), "You should think of the opposite" (Livia) and "You and me, for example Joris and Livia, all the best ideas are put in a cooking pot." They also developed a

vocabulary around fixation ("get hooked on to an idea", 'sticking to",) and about getting past fixation (empty your head, reset your mind).

Self-reports on the effect of the visualization tool and the pause

To establish the effect of the pause, brainstorm results from the first and second brainstorm round were compared. The amount of ideas dropped from 32 on average per team in the first round to 16 in the second round. The ideas in the second round are more elaborated, which is according to Guildford a measure of creativity. However, the level of variety and uniqueness of the ideas could not be compared objectively because the ideas were not clear enough to be analysed.

The self-reports given in the post-interviews are summarized in table 1. All seven students mention positive effects of the pause on their second brainstorm. They also refer to specific icons or advises given during the pause. This was mostly spontaneous, but prompted by the interviewer in a few instances.

As described before, Joris realizes his fixation and reports that he was able to change his thinking processes in the second round. Livia mentions that she was able to think divergently in both rounds and she did not notice large differences. However, she started to apply the advice to think about opposites after the pause and the pause helped her to 'reset" her mind. She also developed new strategy to combine elements: *"I was really running out of ideas as I had used all the picture-cards. And then I picked two picture-cards and laid these near each other. And then I discovered that I could combine these…."*

Lana and Lianne found the pause helpful and used the icons. Nevertheless Lana judges her first round as the one with the most ideas. She evaluates her both rounds as equally good in terms of variation because in the second round she would often think "Oh*, I have this idea thought of this idea already, I have thought of it already, I have thought of this idea already. What should I do now?*

Lianne gave during the reflection her class the tip "to persevere" and applied it herself in the second round.

Lianne:	"Don't give up."
Interviewer:	"Don't give up. How did you apply that in the second round? Or did you apply it?"
Lianne	"Yes, at a certain point I was not able to generate an idea. And I was thinking …what should I do with this picture and then I quickly took a second picture and then I developed a small idea, an idea with it. And I received many ideas, also in combination with the earlier picture."
Interviewer:	"So you generated new ideas by combining two ideas, do I understand you well?"
Lianne	Yes."

Denise and Sophie report less ideas in the second round because it was more difficult to generate ideas related to the design question. However, the ideas were more unusual and related to the design question. Informal contact with students who had unusual ideas, made them realize that they should not judge ideas and this allowed them to generate unusual ideas.

Danique reports that she was able to change her behaviour. She worried less and developed more and a greater variety of ideas.

Table 1. Self-report on change in divergent thinking due to the pause

	Specific icons used in second round*	**Comparing first and second brainstorm on criterium varied**	**Example of a specific impact mentioned**	**Effect of the pause according to the student**
Joris	2, 6 and 7	Second is more varied.	Able to forget about earlier ideas.	Positive
Livia	7	Equal.	Thought more often of the opposite.	Positive
Lana	4	Equal.	Only use of icon 4 mentioned.	Positive
Lianne	1, 4, 7 and 8	Second is more varied.	Able to persevere which results in a new strategy for divergent thinking.	Positive
Denise	8	Second is more varied and more geared towards the design assignment.	Focus divergent thinking on design assignment.	Positive
Sophie	8	Second is more varied and more geared towards the design assignment.	Focus divergent thinking on design assignment	Positive
Danique	8	Second is more varied.	Able to worry less during brainstorming resulting in a behavioural change with respect to picking new pictures	Positive

Note: * explicitly mentioned

Each pupil referred to specific icons that they used during their brainstorm, usually during their second round. Although advice three and five were not explicitly referred to, the interviews show that the students had internalized them. All students report a lower ideational fluency (amount of ideas in a certain time period) at the end of the second brainstorm as they had already used all pictures from the envelope.

Five students judge their second brainstorm as more varied. Livia and Lana report no change in this quality. However, each pupil reports a positive change in divergent thinking due to the visualized learning intentions and the reflection during the pause.

Conclusions and discussion

Visualization of the proposals and way the teacher led the dialogue led to co-development of the learning goal of divergent thinking. This led to an increased understanding of the goal of divergent thinking and students could explain the learning goal of diver gent thinking using their own vocabulary, as well as icons and ideas developed in the class dialogue, which indicates an internalized and comprehensive understanding.

Several factors contributed to the co-development and internalization of the success criteria for divergent thinking. *The visualization of each advice* led to active involvement of all students. This allowed them to think deeper about the learning intention as they thought (collectively) of suitable icons that would explain how sound divergent thinking looks. The tool allowed for the development of their *own vocabulary, both in words and pictures,* e.g. "mixing ideas" for the process of connecting seemingly disparate ideas.

The visualization process led to a *balanced involvement* of the teacher and the students. Although all advice was coined by the pupils, the teacher guided the students towards a sound sense of quality, for example by sharing information about the outcomes of divergent thinking and by exposing misconceptions.

Whenever misconceptions were voiced, the teacher acted as *gate-keeper* by asking if certain suggestions really led to divergent thinking. As a result, students were able to think their advice over. *Exposing misconceptions* is not common when learning intentions are shared. However, knowing what one should not do is also extremely important as we know from experiments in the tradition of behavior modelling, people who are given both good and bad examples during a training perform better, especially in daily practice (Kitsantas, Zimmerman, & Cleary, 2000; Baldwin, 1992).

Quite often, learning goals are shared by teachers without it being clear whether students understand them (Gulikers & Baartman, 2017). The visualization of each contribution gave the teacher the *opportunity to check if the shared success were clear* to the class. In this class, *good conceptions of divergent thinking* were present amongst students and these were collected and clarified for everyone. We assume that made the success criteria relevant and understandable. *The way the teacher guided the sharing of advices*, taking time for *paraphrasing, asking, elaborating ideas and involving the whole class*, resulted in a *shared* framework. This is especially clear from the post-interviews in which the students refer to the icons and use vocabulary from the pause.

All students interviewed developed a sense of quality and used this to forward their divergent thinking process in the first round and even more so in the second round. Of course, they have not yet a complete insight in how sound divergent thinking may look, e.g. the concept of originality was not clear to most of them. There are thus limitations to the use of the tool "Visualize a design skill." When students generate success criteria for a skill, some elements may be underrepresented. However, this does not have to be a problem, as teachers can clarify these unknown aspects in another design activity. According to their own perception, the majority of the interviewed students were able to use the collective diagnosis and feedback to improve their divergent thinking. Although the reported change did not always have a huge

impact on the quality of the brainstorm results, it was always an important step forward in developing adequate divergent thinking behaviour.

The feedback uptake is remarkably effective, compared to what is known about feedback, e.g. students ignoring feedback or other adverse reactions (Wiliam ,2018; Dweck, 1975; Kluger, & DeNisi, 1996) and in design education (Schut et al. 2019; Troxler, & Klapwijk 2018).

An explanation could be students were the *main contributors in the diagnosis and feedback activities*, the input of the teacher was limited. Successful teachers tend to *allow more student steering* during the discussions, reacting on what students say (Buck, TrauthNare &, Kaftan, 2010, Ruiz-Primo, & Furtak, 2006; Ruiz-Primok & Furtak, 2007). This is what the teacher did, students came with the issue of fixation and with relating a brainstorm to the design question. The self-diagnosis shared stimulated the meta-cognitive thinking of other students as they recognized similarities as well as differences when comparing their divergent thinking processes with those of other students.

There was f*reedom* to pursue different approaches to divergent thinking. Each icon was an advice that could be used, but not necessarily something that one had to do. Students could thus select and use the icons and feedback advice that was relevant for them and neglect others. We also assume their specificness led students to the hope that they were able to change their thinking process.

The focus on one design skill and the limited numbers of advice (8 icons) made the diagnosis and feedback manageable. It is clear that students in the second brainstorm round focus on improving only one or two elements that are relevant for them. Many studies indicate that self-assessment and peer-assessments are strong instruments as long as the teacher structures and steers the assessment (Restrepo, 2013; Willis, 2011; Wylie, & Lyon 2015), this is exactly what teacher Katy did as she used the product-criteria (many, varied, new) and the process-icons to structure the reflection.

Our case study emphasizes the value of enabling students to develop their own terminology as a way to engage them in assessment. The research results indicate that using a visual tool to clarify and share design goals in an interactive way is very beneficial and creates a good foundation for self-assessment in a collective setting. This happened in one class with one specific teacher who is strong in allowing student steering. Additional quantitative research is needed and objective comparisons of the generated ideas before and after interventions.

Our case study shows how clarifying, sharing and understanding learning intentions related to design skills during complex design and technology processes (strategy A) provides a foundation for the next four formative assessment strategies were students elicit evidence (B), diagnosis their own progress with respect to a specified design skill (B) and use feedback to move the learning forward (C). Learners were a source for each other (D). And as they personally selected something to become better in during the second brainstorm, they became owners of their own learning (E).

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Appendix 1 Overview of design skills

An overview of the design skills used in "Make Design Learning Visible" that were formulated for teachers are given. These skills are also described for students on cards using pupil friendly language.

THINK IN ALL DIRECTIONS

Students generate many, diverse and original ideas. They combine, associate and imagine. They seek inspiration in unusual places and look at problems from different perspectives. And most important, they postpone their judgement.

› **Many** – come up with a lot of relevant possibilities, solutions and ideas.

› **Diverse** – think from different viewpoints and try out various directions

› **New connections** - associate, combine and make new connections.

DEVELOP EMPATHY

Students empathise with and understand other users. They experience the problem themselves, investigate the users and context and actively seek input and feedback. They focus on the user's wishes.

› **Experience** - Experience the problem yourself, identify yourself with the problem, users and stakeholders.

› **Target group** - Research the user and context through field research and use the findings in their design process.

› **Active** - Involve users and stakeholders in their design process and actively seek input and feedback (context mapping, co-creation, testing).

BRING IDEAS TO LIFE

Students express and elaborate their thoughts and ideas in appropriate, meaningful ways and use tools such as stories, drawings, models and prototypes. Making ideas tangible is not only essential for sharing them, it is how you think and learn.

› **Express** - Depict ideas and insights for yourself and others.

› **Develop** - Make ideas as concrete as necessary in order to share them and make decisions.

› **Model** - Use media related skills, including drawing, visualisation, drama, storytelling, simulation, modelling, (prototypes) making and computer programming.

SHARE IDEAS

Students share their ideas and collaborate within their team. They involve users and other stakeholders in their design process and they look for collaboration with people outside the process to improve, spread and implement their ideas. They design together.

› **Letting go** - Share your own ideas: find the balance between letting go and staying true to an own idea

› **Complement each other** – Be open to each other's ideas, complement and help each other.

› **Outward** - Involve people with various backgrounds (inside and outside the process) for feedback, support and guidance. Inspire others.

DECIDE ON YOUR DIRECTION

Students organise their ideas and develop an overview of their project. They form an opinion about the essence of the problem and the desired quality of the solutions. They decide on their design direction.

› **Validate** - Form your own opinions, dare to make value judgments, aim for your ideals and take balanced decisions.

› **Overview** – Order all the generated ideas and information collected to provide an overview and use this to make decisions on the design direction.

› **Focus** - Determine your vision, focus on the core and draw conclusions

MAKE PRODUCTIVE MISTAKES

Students try out- at the earliest possible stage - their beliefs, ideas and solutions. They deliberately apply different approaches, techniques and resources. They iterate and use mistakes to learn from.

› **Try out** - Try out as many things as fast as possible. Search deliberately search for mistakes and deficiencies.

› **Learn from mistakes** - Recognize and acknowledge failures. Investigate, comprehend failures and use them to improve and learn.

› **Deal with frustration** - Learn to deal with uncertainty, ambiguity and frustration.

MAKE USE OF THE PROCESS

Students switch between different ways of thinking within the design process. They steer the process and switch between divergent and convergent thinking, nonconformity and cooperation, abstract and concrete thinking.

› **Process knowledge** – Understand the processes of designing and different techniques. Use these in appropriate ways.

› **Reflection** - Reflect on design processes and use feedback for improvement.

› **Self-knowledge** - Discover and develop own skills, design approach, preferences and most suitable methods for you and your project.

Appendix 2 Overview of tools "Make Design Learning Visible"

Formative Assessment Strategy	Tools
A. Clarifying learning goals and design skills	1. Practice your skills 2. Symbols for design learning: 3. Evaluate examples in advance 4. Visualize a design skill
B. Eliciting evidence of learning	5. An extra touch to "show and tell' 6. Photo storyline 7. Student reporter 8. Golden frame
C. Providing feedback that moves learning forward	9. Perseverance cup 10. On the right track? 11. What isn't working yet?
D. Activating learners as resources for one another	12. Suggestions wall 13. Library of inspiration 14. Students as experts 15. Matrix of skills
E. Activating learners as owners of their learning	16. Traffic lights 17. Card about yourself 18. Group design results 19. Obstacle game

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25.3

Development of teacher education students' pedagogical content knowledge (PCK) through reflection and a learning-by-doing approach in craft and technology education

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Abstract
The approaches of learning by doing and making have always been inherent components of Finnish craft and technology education. Craft is a practical subject that involves many hands-on activities during which students actively practice experimentation, investigation, invention, problem-solving and designing skills. The same ideology is utilised in craft and technology teacher education courses at the University of Jyväskylä. The overall purpose of this study was to increase our understanding of the development of teacher education students' pedagogical content knowledge (PCK) in craft and technology education through reflection and the learning-by-doing approach. To achieve this goal, students were asked to fill out a reflective questionnaire after one of their hands-on working sessions. The open-ended questionnaire was formulated on the basis of Roberts' (2012) four philosophical stances so that each of them were equally able to provide representative information in relation to students' reflections on it. During the academic year 2019–2020, a total of 115 students responded to the questionnaire while taking the 'Pedagogy of Multi-material Craft and Technology Basic Course'. Data were analysed by identifying themes based on the frequency of their occurrence. Philosophical stances of '*knowledge acquisition is inherently interactive*' and '*examining things based on practical consequences*' proposed by Roberts (2012) were the most evident ones in teacher education students' reflections. This study demonstrates how the learning-by-doing approach and use of a reflective tool can facilitate the development of students' PCK in craft and technology education.

Key words
Technology education, craft, learning-by-doing, reflection, PCK, teacher education

Introduction
Over 30 years ago, Brown, Collins and Duguid (1989, p. 32) raised concern on how knowledge is treated as "an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used". Saito (2018) refers to the same problem by introducing the concept of "beautiful knowledge", which means "the experience of knowing, undergoing the moment of self-transformation. More as a matter of reception rather than acquisition, it involves the experience of human transformation undergoing the phases of crisis" (p. 143.) In relation to technology education contexts, researchers have pointed out how practical learning

during technology education lessons helps students conceptualise knowledge and develop various intellectual processes (Gibson, 2019; Ritz & Fan, 2015). Furthermore, a variety of cognitive skills and higher-order thinking skills can be developed and nurtured through their application in practical contexts (Strimel, 2019; Williams, 2009, p. 248). Thus, the domain of technology education provides an important proving ground for theories of cognition, because concepts in technology are often taught through laboratory-based and other hands-on methodologies (see Hayes & Kraemer, 2017). Barlex and Steeg (2018, p. 343) describe learning as a process whereby understanding is built upon already existing knowledge. They argue that this process is most powerful when the construction environment is rich and ample opportunities are provided to view the success of one's construction efforts.

Hands-on nature and practical approaches to learning are emphasised in Finnish craft and technology education, and it is evident that the learning-by-doing approach is an inherent component of craft education (Niiranen, 2019). During craft lessons in schools, students are guided so that they can design and produce their craft products independently and/or with others by using a diverse range of techniques, tools, machines and equipment. In this pedagogical strategy, examining and problem-solving skills are seen as integral parts of learning. (National Core Curriculum for Basic Education 2014, hereinafter NCCBE 2014.) Also, the craft and technology education courses offered at the University of Jyväskylä emphasise practical approaches to learning and the pedagogy of problem solving. One of the courses is called 'Pedagogy of Multi-material Craft and Technology Education Basic Course' (3 credits). This is compulsory for all teacher education students, and after completing the course, the students are expected to achieve the following goals: 1) experience success and development of skills, 2) understand the nature of a complete craft process, 3) understand the role and importance of hands-on activities in human development and 4) develop skills to conceptualise the curriculum and utilise them when designing, developing and executing craft education. During the course, students are also expected to reflect on their positions and on the development of three different roles: the role of a craftsman/craftswoman, the role of a crafts teacher and the role of a child as an artisan.

Practical approaches to learning with reflective elements are inherent components of Finnish craft and technology education in schools, and also in courses at the University of Jyväskylä Teacher training department. For this reason, exploring and clarifying how reflective learning and its role in developing student's pedagogical content knowledge (PCK) in this context is important. Thus, the purpose of this study was to increase our knowledge and to provide information about the development of teacher education students' PCK in craft and technology education through reflection and the learning-by-doing approach. This study adds to our understanding of the learning processes wherein teacher education students are tasked to make their own projects. We also aimed to improve the practices in which reflection is being facilitated in craft and technology education.

Theoretical perspectives – reflection, PCK and the learning-by-doing approach

One major factor that brings concepts of reflective learning and pragmatism together in a significant way is that both forms of learning are relatively independent of mediation, and this extends learning beyond formal education (see Moon, 2004, p. 74). Mälkki (2011) points out that although reflection is being widely facilitated in different educational settings, what is actually gained through these efforts is not often evident. Furthermore, reflection is often

triggered by disorienting dilemma or a growing sense of dissatisfaction; however, how this would lead to reflection has yet to be fully explained (Mälkki, 2011). Considering the academic context, reflection and reflective learning are likely to involve a conscious and stated purpose for the reflection, which can yield specific outcomes in terms of learning, action or clarification (Moon, 2004, p. 83). Tracey and Hutchinson (2018) note that reflecting for and from action is relevant in design education, as the goal should be to prepare students for what they will encounter in their future professional practice.

When considering teacher education, the idea of reflection is strongly related to the development of teachers' PCK. As Hashweh (2013, p. 120) proposes "we think of PCK as a set or repertoire of personal content-specific pedagogical constructions which teachers develop as a result of repeated planning, teaching and reflection on the teaching". Although it is difficult to distinguish PCK from other fields of knowledge that teacher displays in teaching (general pedagogical knowledge, subject matter knowledge and knowledge of context) (Gess-Newsome, 1999), patterns help us to analyse the activities or the ways that the development of teachers' PCK could be supported. In their study on primary school teachers' development of PCK in a design-based research project, Hultén and Björkholm (2016) underlined the importance of reflection on one's own actions, making teachers owners of their professional development, in collaboration with others.

There are seven teacher key competence areas that are defined in Teacher education curriculum, University of Jyväskylä 2020–2023. These competences create guidelines to be considered throughout training in teacher education. One of the competences is namely "Pedagogical competence" (competence area 5). According to this competence area, students should be able to: 1) plan, implement, differentiate, evaluate and develop various learning processes, 2) understand the connection between learning objectives, pedagogical activities and assessment in interactive learning and guidance processes, 3) act and think creatively and innovatively and 4) be open to new perspectives, invent, experiment and challenge the familiar. (Teacher education curriculum, University of Jyväskylä 2020–2023.)

Four philosophical stances of learning by doing

Undoubtedly, John Dewey (1859–1952) is one of the most significant figures in the field of experiential education, particularly amongst classical pragmatists; he is known for demonstrating most concretely the contemporary significance of the *praxis* of pragmatism for the reconsideration of useful knowledge and education (Saito, 2018). The concept of pragmatism has been divided into four philosophical stances (Roberts, 2012, p. 49), which are understood to loosely define it. The first stance concerns *examining things based on practical consequences*. In other words, one chooses a course of action according to the likelihood of its success or with an awareness of the consequences of one's actions (Roberts, 2012, p. 50). Learning by doing, in the context of craft and technology education, is accentuated by activities involving problem solving, design and scientific inquiry. The design process in craft and technology education is usually characterised as a goal-directed and iterative activity, whereby the designer learns about the problem by proposing solutions and synthesising ideas (see Purzer, Goldstein, Adams, Xie, & Nourian, 2015).

The second stance of pragmatism (Roberts, 2012, p. 51) states that pragmatists understand that thinking cannot be removed from the world, because *knowledge acquisition is inherently*

interactive. This means that the interactions between thinking and action and how they revise one another are seen as key factors in learning (Roberts, 2012). Thus, the learning process is highly contingent upon interactions with the environment and the people who are related to it. The role of context is of central importance in craft and technology education, wherein interactions with tools, concrete objects and materials offer a potentially supportive environment for collaborative actions (see Hennessy & Murphy, 1999).

The third stance of the pragmatist ethos, *the importance of context* (Roberts, 2012, p. 52), also relates to the learning environment. As described previously, in order to consider practical consequences interactively, one must be situated somewhere. It has been argued that situativity is a dominant perspective in technology and engineering disciplines—one that emphasises the role of the environments and requires extensive content knowledge and analytical skills to engage in learning (Hennessy & Murphy, 1999; Johri & Olds, 2011; Pleasants & Olson, 2018). Problem solving, project-based learning and creating things with the use of one's hands are evidently inherent components (i.e. methods for learning) of craft and technology education (Niiranen, 2019; Kilbrink, Bjurulf, Blomberg, Heidkamp & Hollsten, 2014), and each of these pedagogical approaches is innately contextual. Thus, when learning is grounded within a specific context, it is often authentic, relevant and representative of an experience that may be found in practice (Kelley & Knowles, 2016).

The fourth stance of the pragmatist ethos is *fallibilism* (Roberts, 2012, p. 52), which means that errors are seen as part of the learning process and are an inherent part of technology education. This idea relates to an interesting characteristic of technology education: the high degree of tacit knowledge inherent in it. Tacit knowledge and skills, i.e. understanding how various materials behave and knowing how to manipulate them, can be gained only through concrete experience, although some errors are often made during the process of making. The concept of tacit knowledge also adheres to the concept of embodied cognition as both emphasise the body's role in forming cognitive representations. By action, one's cognitive systems are affected—even constrained—and these sensorimotor processes, including perception and action, strengthen learning when included in a structured lesson because of their close and unique relationship to the cognitive system (Weisberg & Newcombe, 2017). As Gibson (2019, p. 27) describes, tacit learning happens most often 'on the job'. Thus, hands-on activities are sometimes seen as a 'black box' in learning, and what students have actually learnt might be hidden (Kuen-Yi & Williams, 2017).

Research design

The aim of this study was to increase our knowledge and to provide information about the development of teacher education students' PCK in craft and technology education through reflection and the learning-by-doing approach. Data were collected by using an open-ended reflection questionnaire distributed to students enrolled in the 'Pedagogy of Multi-material Craft and Technology Basic Course'. Students were asked to provide reflections on an optional questionnaire (in paper) at the end of one three-hour hands-on working session (8th session). The open-ended questionnaire was formulated on the basis of Roberts' (2012) four philosophical stances and the questions were designed to provide equally representative information, with three questions per stance, concerning their special nature (see Table 1). In the questionnaire, there were 12 open-ended questions to choose from, and the students were encouraged to answer multiple options (i.e. to report all they could recall). No identification

information was asked from the participants. During the academic year 2019–2020, between 3.9.2019–13.3.2020, a total of 126 classroom teacher education and special education students (eight groups) signed up to participate in the course. Almost all (91%) of the students responded to the questionnaire.

Table 1. Four stances of learning-by-doing by Roberts (2012) and the questions modified for the craft and technology education students (see also Niiranen, 2019).

Examining things based on practical consequences
One chooses the right course of action based on the likelihood of success, or with an awareness of the consequences of one's actions. In craft and technology education, learning by doing is accentuated by activities involving problem solving, design and scientific inquiry.

Q1 I solved a problem: *What kind of problem?*
Q2 I chose one technique from many options: *Which one and why?*
Q3 I ended up doing something contrary to my plan: *What did I change?*

Knowledge acquisition is inherently interactive
The interactions between thinking and action and how they revise one another are seen as key factors in learning. Thus, a learning process is highly contingent upon interactions with the environment (craft and technology education classrooms) and the people who are related to it.

Q4 I asked for help from others: *What did I need help with?*
Q5 I helped someone to make something: *How did I help?*
Q6 I designed or developed my work together with others: *What did we design?*

Fallibilism
Errors are seen as part of the learning process and an inherent component of technology education. High degrees of tacit knowledge and skills, i.e. understanding how various materials behave and knowing how to manipulate them, can only be gained through concrete experience.

Q7 I made a mistake in measuring or marking: *What kind of mistake did I make?*
Q8 I chose a wrong tool: *What happened?*
Q9 I made some other kind of a mistake: *What kind of mistake did I make?*

Importance of context
In order to consider practical consequences interactively, one must be situated somewhere. Situativity is a dominant perspective in technology and engineering disciplines. Problem solving, project-based learning and creating things with the use of one's hands are inherently contextual.

Q10 I learnt to use a new tool: *Which tool?*
Q11 I used some machines during working: *Which machines?*
Q12 I learnt something about the properties of materials: *What did I learn?*

The syllabus of 'Pedagogy of Multi-material Craft and Technology Basic Course' includes 10 sessions (3 hours per session), which are compulsory for all students. The course consists of various modules, such as a module involving a hands-on working session, wherein students implement their projects in technical and textile craft workshops. The logic for choosing the 8th session, i.e. one of the hands-on sessions, to conduct this study was due to it being the first session, where students will actively start to implement their individual projects. During previous sessions, students have familiarized themselves with the various craft (textile and technical) materials, tools, techniques and machines on a general level. Thus, they should be able to use them rather independently when working with their projects. The overall idea in the 8th session is that students are encouraged to independently use all necessary materials, tools and machines to implement their projects and to solve various authentic open-ended problems in collaboration with peers. While students are working, they are guided to take ownership of both implementing their own craft project and developing their personal pedagogical content knowledge in craft and technology education. The teacher's role is to supervise students in terms of work safety and to give guidance and support when it is needed.

As the research approach was theory-driven and has fairly clearly defined attributes, a quantitative approach was used to analyse the data. The primary aim was to investigate and discover themes based on the frequency of their occurrence. Quantitative content analysis was chosen to be the analysis method as it enables the illumination of patterns in a larger set of communication content in a reliable way (Rourke & Anderson, 2004). By doing so, data comprising 115 students' written responses were analysed using the frequentist descriptive method, which aimed to identify students' descriptions concerning questions 1–12. First, all responses to a single item were read through and students' responses were calculated as frequencies in relation to how many of them answered each question (see Fig 1). Then, meaningful descriptions or manifest content were chosen as the analysis units and those were listed by assigning each contribution under a category. During this coding process, the researcher used both quantitative and qualitative analyses to process the survey items in order to develop the categories. This was done to ensure that the students' responses were appropriately captured. After the coding, the categories were grouped into sub-themes, which emerged from the data. Such a content analysis, in order to be reliable, requires that the coder understands the context i.e. how to identify behaviours and the representative samples that represent the construct (Rourke & Anderson, 2004, p. 9). In this study coding was performed by a researcher who knows the context of the study well as she has acted, in previous years, as a teacher in the course. The identified sub-themes within each question (1–12) and their relations with the four philosophical stances proposed by Roberts (2012) will be presented in the results section.

Results

The following findings are tied to certain elements and contexts wherein students were asked to provide reflection at the end of a three-hour hands-on working session in the 'Pedagogy of Multi-material Craft and Technology Basic Course'. The projects that students were working on included the use of basic hand tools, such as hand saws, chisels, mechanical drills, hammers and screw drivers. Many woodworking techniques were used (e.g. making a nail/screw or doweled joints, welding, turning wood), and some students have also chosen textile techniques (e.g. knitting and sewing). Students used various machines, such as drilling and sanding machines, band saw, thickness planer for wood and lathe while working. In the following section, four

philosophical stances of learning by doing and the findings of the reflective questionnaire are presented.

When investigating students' responses to the reflective questionnaire 'What did I do in today's craft education contact session'? the questions with the highest frequencies were questions 4, 5 and 6 with altogether 282 responses (see Fig 1). These three questions reflected the second stance of pragmatism, namely, *knowledge acquisition is inherently interactive* (Roberts, 2012). Almost all (93%) of the students provided reflections to the question 4 (I asked for help from others: What did I needed help with?). Based on the students' reflections the most representative sub-theme was 'Using the woodworking machines'. The second most representative sub-theme was 'Performing a technique with a certain material and how to proceed with working'. As evidenced in a previous question, whether students asked for help from others, reflections on question 5 revealed that they also helped each other. Many (82%) of the students answered question 5 (I helped someone to make something: How did I help?). The most representative sub-theme was 'With the use of the woodworking machines' and the second most representative sub-theme was 'With the design or working with the different tools and techniques'. Also, many (70%) of the students responded to question 6 (I designed or developed my work together with others: What did we design?). The most representative sub-theme in relation to this question was 'Planning collaboratively how to implement the project' with the next one being 'Designing the project together'.

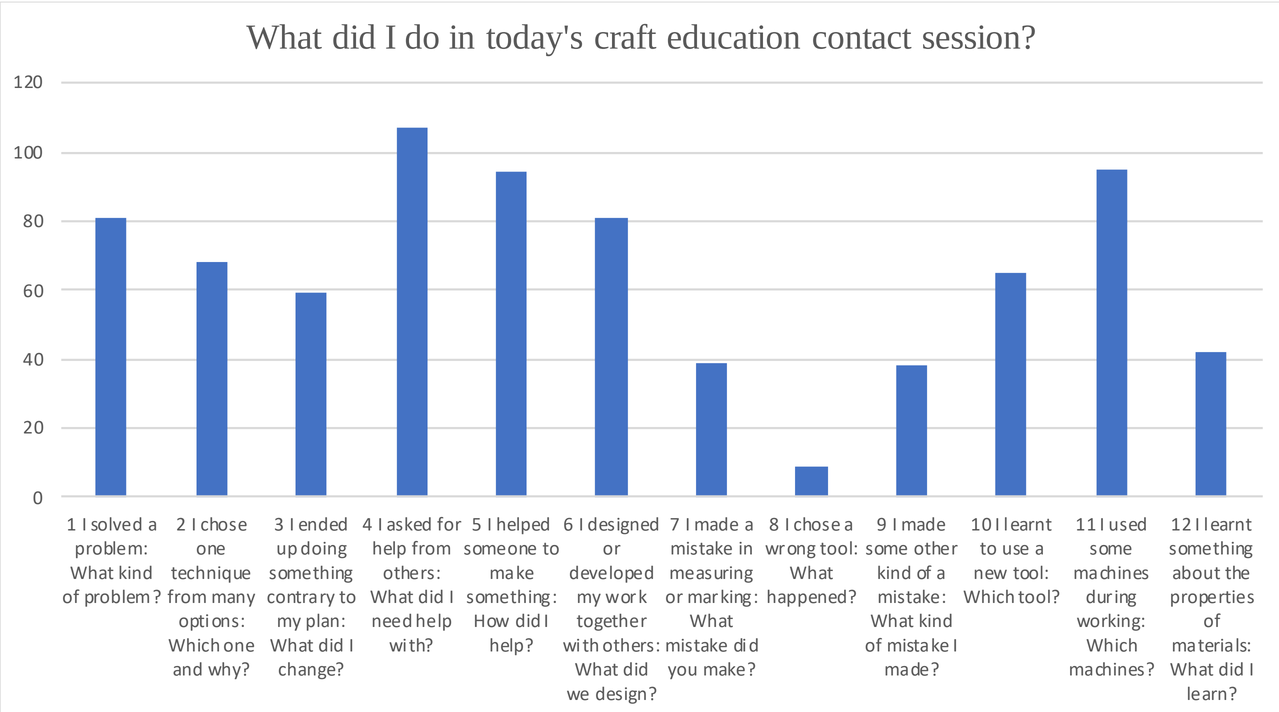

Figure 1. Students' responses to the questionnaire items (N=115)

The second highest frequencies were calculated with questions 1, 2 and 3, altogether 208 responses. These questions reflected one of Roberts' (2012) philosophical stance of pragmatism, namely *examining things based on practical consequences* (see Fig 1). Many (70%) of the students responded to question 1 (I solved a problem: What kind of problem?). Based on the students' reflections, the most representative sub-theme was 'Ideating and designing the

project (materials, measurement)'. The second most representative sub-theme was 'How to implement the technique by using a machine. The ideas were related for solving the problem related to a specific technical question, like how to saw the pieces, drill a hole or smooth the wood, use the right kind of sanding machine, turn wood or how to knit or sew and when students needed to use various machines or tools for making something. More than half (59%) of the students answered question 2 (I chose one technique from many options: Which one and why?). The most evident sub-theme was 'To use a machine in order to implement the technique better and faster'. Other reflections for this question were mainly related to the sub-theme 'Trying some different techniques and tools'. Also, half (51%) of the students responded to question 3 (I ended up doing something contrary to my plan: What did I change?). The most representative sub-theme was 'Finding some new ideas, whilst working on the project'. These ideas were related to using a different way to fasten the pieces, making smaller/bigger projects or changing the material and/or the surface treatment in their project.

In relation to the stance of *the importance of context* (Roberts, 2012) (questions 10–12), there were altogether 202 responses. Concerning students' reflections on question 10 (I learnt to use a new tool: Which tool?), more than half (57%) of the students responded that they became more familiarised with and confident in using the machines; however, these machines were not new for all students. The same can be evidenced when many (83%) of the students answered question 11 (I used some machines during working: Which machines?). The use of various machines depended on the project. However, for many projects, it was necessary for students to use common ones, including the thickness planer, band saw, drilling machine, sanding machines and some used the mechanical jigsaw, lathe, laser cutter or welder. In addition to using machines and hand tools, some students (37%) answered question 12 (I learnt something about the properties of materials: What did I learn?). Naturally in this context, these reflections mainly concerned the properties of wood (pine of plywood) and some about metals (aluminium and steel) or textiles.

There were also three questions (7, 8 and 9) related to *fallibilism* (Roberts, 2012). Some (34%) of the students responded to question 7 (I made a mistake in measuring or marking: What kind of mistake did I make?). The students wrote such comments as: *"I had measured one piece of my project too long", "I measured incorrectly and had to saw again", "The hole came a little wrong when I didn't measure carefully enough" and "At the point when I was trying to start with old measures, I marked sawing places that weren't worth taking".* Only a few (8%) answered question 8 (I chose a wrong tool: What happened?). Those who reported something related to this question had chosen a right kind of tool or machine for making something, but it proved inadequate at some point (e.g. the file was too rough or the piece to be sawed was too huge for the band saw). Some (33%) of the students responded to question 9 (I made some other kind of a mistake: What kind of mistake did I make?). Students made reflections through the following comments: *"I sawed too close to the marked line and the piece got smaller", "I sanded one corner too much so it became a bit different", "I sawed the piece before using the thickness planer, so I had to make new on", "I should have supported my work better, so there wouldn't have been that ugly mark. By sanding, however, it got better" and "I burned the pattern unevenly when inadvertently the wood burning pen was too powerful".*

Reflective questionnaire as a way to support students' learning in craft and technology education

One philosophical stance (i.e. *knowledge acquisition is inherently interactive*) proposed by Roberts (2012) appeared to be the most evident in teacher education students' reflections when they responded to the questionnaire after their hands-on working session. Almost all students (93%) reported asking for help from other students for using the machines that they needed for their work or for instructions regarding performing a technique with a certain material they were unfamiliar with. In addition to that, many (82%) reported that they helped others with the use of the woodworking machines, and/or with the design or working with different tools and techniques. Also, many (70%) of them reported that they planned collaboratively on how to implement their projects (e.g. in terms of its structure and the design). This finding supports the idea that problem-based learning can facilitate knowledge transfer, encourage and support collaborative work and improve students' thinking and designing skills (Fain, Wagner & Vukasinovic, 2016). Also, as today's learning environments and pedagogical decisions should support the use of modern teaching and learning processes and when students are encouraged to work like this, they are prepared to understand the role of a teacher and peer-interaction during an authentic problem-solving process. Thereby, we claim that this type of working will help students to develop their PCK in craft and technology education.

In relation to the philosophical stance of *examining things based on practical consequences* (Roberts, 2012), we found that this was also strongly present in students' responses. Many (70%) of the students reflected that they solved problems related to ideating and designing the project and/or how to implement the technique by using a machine. Furthermore, over half (59%) of the students reported using machines in order to implement the technique better and faster and/or that they tried some different techniques and tools. Also, a little over half (51%) of the students reported that, whilst working on their project, they found some new ideas (e.g. a different way to fasten the pieces) or they ended up making smaller/bigger projects or even changing the material and/or the surface treatment of their project. As making and practical approaches to learning are emphasised in the NCCBE 2014 craft subject (Niiranen, 2019) and at the University of Jyväskylä craft and technology teacher education, this finding supports the view that through the learning-by-doing approach, students can be encouraged for problem solving and systematic inventive thinking (see Barak & Albert, 2017). Although this finding revealed that more than half of the students recognize and solve problems during working with their project, we cannot be sure how they understand the pedagogical aspects of a problem-solving process and which are those key questions that teachers should take care of when planning activities for their pupils. As teacher educators, we might lean too much with the idea that students make connections themselves of their own working and with the pedagogical aspects i.e. they read the 'hidden curriculum' of the 'Pedagogy of Multi-material Craft and Technology Basic Course'. Thus, in order to emphasize the pedagogical aspects and help students to better develop their PCK, we should add stronger links with the pedagogical aspects by making them more visible in students' reflections.

There are some limitations in this study and in order to understand how to better support students for developing their PCK, more research is needed. On one hand, this study was limited to investigate students' reflections in written form on paper. Future research may

include interview as a data collection method to elicit students' reflections on the development of their PCK. Besides, future studies can be conducted to investigate how a reflective questionnaire would be utilized in various ways, in an electronic form, during the 'Pedagogy of Multi-material Craft and Technology Basic Course' or other courses.

These findings provided an important contribution by explaining the conceptual connections amongst the cognitive and social aspects of craft and technology education in teacher education. Using this kind of reflective questionnaire as a research tool offered us a way to improve our educational practices to further develop also students PCK. In order to ensure this, we will add some pedagogically oriented questions e.g. 'What did I learn pedagogically in today's craft education contact session?' to the reflective questionnaire in the following academic year. In addition to that, at the end of the course, students will be asked to write reflections on the development of their pedagogical competence in relation to craft and technology education course to their electronic professional development portfolio (Prope). Finally, as a recommendation for technology educators, by emphasizing a learning-by-doing approach with reflective elements, students' PCK and thereby also pedagogically oriented key questions can be made more visible and a stronger part of craft and technology education.

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A Toolkit for Practice-Based Learning of Mechanisms in Industrial Design Education: An Application of a Method Combining Deductive and Inductive Learning

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Abstract
Industrial design education is focused on teaching a combination of various interdisciplinary competencies. One of these projected learning outcomes is to be able to design mechanisms in order to fulfil certain mechanical constraints in products. Studies show that theoretical knowledge supported by practice helps to teach industrial design students the mechanisms. In the current situation in Turkey, practice-based courses are designed with a similar purpose. However, graduates severely lack mechanical design skills. In this study, a two-staged toolkit of a holistic flow is introduced to prevent the deficiency mentioned above. In the toolkit, mechanisms are taught by combining deductive and inductive approaches, instead of a directly inductive conventional approach. The toolkit is applied to 36 sophomore year students. Assessments of the students and their self-evaluations are collected and analysed. Findings show that the toolkit can be beneficial for teaching of mechanisms to ID students through some revisions.

Key words
design education, learning methods, experiential learning, inductive learning, learning of mechanisms

Introduction: Motive of a Toolkit
Paradigms of industrial design (ID), which is a crafts-based discipline (Başar & Ülkebaş, 2011), is shifting, while communication and information technologies are developing (Overbeeke, Appleby, Reinen & Vinke, 2004). Universities offer diversely structured ID programs. Research or practice-based approaches are already separated (Friedman, 2002; Zeng, 2017). The profession of ID is branching out and graduates posess various competencies (Domermuth, 2009). The scope of these competencies (Siegel, 2000) and approaches for evaluation of these skills (Horváth, 2006) are discussed in studies. However, discrepancy of expectations of the students, universities and companies from various industries (Erkarslan, Kaya & Dilek, 2011; Domermuth, 2009) shows that a universal approach for developing certain competencies is not likely to be found.

The Interdisciplinary essence of this profession necessitates an education that is based both on theoretical knowledge and practice. However, educational approaches are controversial. For educators, a holistic view is regarded as innovative (Horváth, 2006). However, the focused qualifications that a reductionist approach provides are still valuable for employers (Erkarslan,

et al., 2011; Kındı, 2007). Reductionism assumes that comprehending components is enough to understand complex systems (Horváth, 2006). Contrarily, a holistic approach considers the net of relations between individual elements of the system in order to determine them. Companies expect to hire designers with mechanical engineering based skills. However, they argue that graduates lack these competencies. (Erkarslan, et al., 2011; Domermuth, 2009; Yang, You & Chen, 2005; Kındı, 2007). The topic is controversial. While some of the studies criticize employers for misunderstanding the ID competencies (Erkarslan, et al., 2011), others denounce conventional educational models for lacking experiential learning contents (Roozenburg, Van Breemen & Mooy, 2008; Bingham, Southee & Page 2015; Yavuzcan & Şahin, 2017).

Engineering courses are limited in ID education compared to the engineering programs. Particularly in Turkey, conventional methods for teaching engineering knowledge to ID students are inefficient, often reductionist, and there is a need for optimizing the practice-based learning approaches (Yavuzcan & Şahin, 2017). Howard (1997) remarked that only a few institutions in the USA grant degrees in ID engineering while there are many design and ID departments. Very few of the programs offer engineering courses unless they include “engineering” in their titles or are established within an engineering program. Universities often focus on an interdisciplinary integration but none of them meet the ‘sweet spot’. Howard uses the term sweet spot to describe a presumptive ideal combination of disciplines in an ID program. However, the formula of an ideal curriculum is unknown, and it makes the sweet spot a utopian ideal. On the other hand, Howard’s criticism is likely to remain valid in Turkey. Manifestos of some of the most renowned Turkish ID programs lack or consciously avoid integrating engineering. Even when added, engineering content in their curricula is often theoretical.

What engineering knowledge is and how it is related to ID are other questions of debate. Engineering practice is a systematic problem defining and solving process which is fuelled by specialized knowledge and an ability to integrate that knowledge into the process (Sheppard, Colby, Macatangay & Sullivan, 2006). Current approaches focus on teaching engineers to conceive, design, implement and operate complex systems within a sustainable and responsible framework (Crawley, Malmqvist, Östlund & Brodeur, 2007). Defining the current state, the attributes and constraints and developing a means-end chain is how engineering practice works as a problem-solving process. There are infinite numbers of ways to solve a problem. Comprehending them is “knowing that”. Implementing the efficient one is “knowing how”. “Knowing how” is what makes engineering knowledge identifiably different from scientific knowledge. (Sheppard, et al., 2006). The nature of engineering is often perceived as finding an optimal solution. However, some of the researchers argue that the solution should only be satisfactory. Rather than looking for an ideal design, engineering should be holistic, iterative, communicating with other disciplines, affected by cultural norms, considering the needs of society and able to integrate scientific, mathematical and social values and theories (Pleasants & Olson, 2018). The nature of engineering and definitions of ID overlap in these terms. However, engineering education is currently focused on teaching “knowing how” in a holistic manner, whereas engineering in ID education is limited to theories of mechanical engineering, materials and manufacturing.

The ID department of Gazi University is an exemplary case for Turkish ID education, as it is one of the few state universities which has include an ID program for around a decade and applies a generic curriculum. Several years ago, the second year design studio of this program was

following a common approach. This common approach is focused on practice-based inductive learning. Inductive learning is a specific-to-general learning method, the opposite of deductive learning, and it is often hands-on learning (Prince & Felder, 2006). Lecturers observed that after completing heavily theoretical engineering lectures, attending a course based totally on inductive learning is compelling for the students. Besides, during the assignments of the design studio, the sophomore year students benefit only a little, if any, from the knowledge which theoretical courses aimed to teach them. The essential question of the study has originated from the criticism above: if the transition from one learning approach to the other is optimized to be more structured, would the education of engineering knowledge be more efficient for ID students?

A toolkit was developed regarding the mentioned discussion. It includes a two-stage guide for a project assignment: a semi-deductive pre-assignment and a subsequent semi-inductive design assignment. After taking a few theoretical deductive learning style courses in engineering, students were given the toolkit assignments. The study is focused on observing the participants during the application and receiving post-evaluations from them. 36 students and 5 instructors participated in the research. For the pre-assignment, students researched and presented the fundamental functions of the mechanisms. They were asked to design a system of mechanisms, free of sense-making purpose. After practising the mechanisms conceptually, students designed household tools and gardening equipment, considering the constraints of realizing some of the fundamental functions of mechanisms.

Approaches in Design and Design Education

Even though the graduate and the postgraduate education of ID is slightly more than a century old, designing objects or structures can be traced back to the beginning of humankind (Friedman, 2000; Heskett, 2005). The simplest description of designing can be depicting or planning (Tarelko, 2006). Considering that any human-made object can be planned, the scope of design is immense, and limits of its extension are undefined. Behind every artefact there is a set of conscious and unconscious decisions made by designers (Walsh, 1996; Vial, 2015). While sources of knowledge are democratizing, anyone can design, yet what anyone designs is not always good design (Papanek, 1985; Atkinson, 2006; Vial, 2015). Even though being formally educated makes a designer competent (Gorb & Dumas, 1987), skills which an educated designer should have is a question of debate.

Origins of Industrial Design

A discussion about the scope of these skills can be made by comprehending what ID is. Natures of engineering and design show similarities. However, art is what separated ID from engineering in its origins (Findeli & Benton, 1991). ID is a profession originated from artisanship (Başar & Ülkebaş, 2011). It was pioneered by the Arts and Crafts movement (Weingarden, 1985), which objected to machines for taking the spirit out of crafts (Weingarden, 1985). However, the art centered and bohemian early stance of the Bauhaus was changed to a conventional educational approach towards the mid-20th Century. The apprenticeship orientated basis of ID programs has transformed into a more standardized university curricula. Since then, art has been losing priority in the pedagogical approach.

(Findeli & Benton, 1991). However, the priority has not shifted to engineering discipline. Besides, art should not be perceived as an opponent of engineering. Art in ID should be regarded as practising engineering aesthetically. Aesthetics is often assumed only as a visual issue, yet it refers to any kind of sense perception (Faste, 1995), being attractive or beautiful (Photiadis & Souleles, 2015; Filonik & Dominikus, 2009). When art lost its priority, engineering in ID education became more theoretical, less practice based (Weingarden, 1985), briefly not aesthetic, less beautiful.

Design Methodology

Along with their overlapping natures, engineering and ID are also related to each other in recent history. This can be observed in the history of the "design methodology movement". According to Cross (1993), the 1962-1970 era of design methodology is the first generation, mostly based on heavily rational methods. The second generation changed the omnipotent behaviour of the designer, popularized user-centred methods such as participatory design, experimental design, usability, accessibility and universal design (Kreuzbauer & Malter, 2005; Kensing & Blomberg, 1998; Iwarsson & Ståhl, 2003). In the 1980s engineering-based design methodology rose andengineering and architectural design methods began to diverge (Cross, 1993). Due to the rise of engineering-based design methods, ID is becoming a more transitional profession by benefiting from architectural approaches as well as scientific engineering methods. According to Grant (1979), there is an opinion among designers that designing is not and will never become a scientific activity. However, some studies show that design can be investigated as a science and science can be within design (Cross, 1993; Andreasen, 1991). The tension is half a century old, yet it remains evident today (Kimbell, 2011). Even though the debate of art and science or engineering was stronger in the first generation, until and during the second generation, researchers started using terms such as scientific design, design science and the science of design. Cross (1993), shared an opinion that the divergence is likely to end in the upcoming third generation. In the 2000s and 2010s, design literature has been introduced to other approaches such as value sensitive design, (Miller, Friedman, Jancke, & Gill, 2007), sustainable design (Blizzard & Klotz, 2012) co-design (Thamrin, Wardani, Sitindjak & Natadjaja, 2018) or the C-K theory (Hatchuel & Weil, 2003). These user-centred theories and methods are based on scientific approaches, thus they validate the expectations of Cross about the controversy of science and design is likely to end. Concluding this section, approaches are classified. Hubka and Eder (1987), describe design science in four fundamental elements: theory of technical systems (1), theory of design processes (2), applied knowledge (3) and theory of design methodology (4). Considering their classification, it is comprehended that design methodology is focused only on theory and practice of design. Thus, design education methodology was researched prior to developing a toolkit based on this classification.

Design Education Methodology

Even though contemporary design practice and education are more complex than they had been in the 1900s, design knowledge still relies mostly on experience. Transfer of knowledge created by experience has shaped a certain teaching approach: apprenticeship (Düzenli, Alpak, Çiğdem & Tarakçı Eren, 2018). ID education has three periods in history, in all of which apprenticeship is fundamental: guild system (1), pre-Bauhaus schools (2), Bauhaus and post-Bauhaus schools (3). As one of the key elements of the present ID education, studio courses of the Bauhaus involve semi-structured experiential learning and hands-on learning methods

which are applied under a master-apprentice relation (Düzenli, et al., 2018; Belgin Dikmen, 2011). Today, particularly in Turkey, studio courses remain in the apprenticeship model. Learning methods benefited in these courses are explained below.

Experiential Learning

There is a series of learning styles in psychology. A pyramid of learning is a summary of these styles (Wood, 2004). Efficiency of lectures is evaluated as only 5% in the pyramid yet practice by doing or making is 75%. Wood (2004) explains the difference simply: the more active subjects are during learning, the more they learn.

Until the mid-nineteenth century, before the experiential learning movement, education, in general, was formal and abstract, in which teachers present and students hopefully apply knowledge (Lewis & Williams, 1994). However, due to the craftsmanship origins, design programs already preferred experiential learning. Consequently, designers have two types of knowledge: conscious and experiential (Leader, 2010). Conscious knowledge is taught verbally or written, commonly and extensively, however experiential learning is individually unique. It is sensorial information, subjective and often implicit (Groth & Mäkelä, 2014).

Learning is a process of creating knowledge according to Kolb and Kolb (2005), sharing similarity with the transition of validated concepts to knowledge in the C-K theory (Hatchuel & Weil, 2003). Learning is relearning in substance (Kolb & Kolb, 2005). Thus, experiential learning is relearning of previously met theoretical knowledge. Designers still need the consciously learned theoretical knowledge, so they can relearn it by doing.

Deductive and Inductive Learning

Experiential learning methods diversify based on their relation to the experience. Learning is deductive or inductive. According to Prince and Felder (2006), deductive learning is conventional and was common once in engineering education. Deductive learning is theory first, experience next, from general-to-specific. Contrary to this, inductive learning begins with observation, experience and case studies, then proceeds to theories. Inductive learning is more likely to be correlated with Kolb's learning cycle: an infinite circular loop of reflective observation (1) to abstract conceptualization (2), active experimentation (3) and concrete experience (4) in order (Kolb & Wolfe, 1981; Kolb, 1984).

Hands-on Learning

The experience of a designer is generally sensorial. He or she must discover a tactile experience with actual materials (Leader, 2010). Touching is the basis of understanding materiality (Sonneveld & Schifferstein, 2009). It is a source of experiential knowledge which can be gained through the making of artefacts (Mäkelä, 2007). The term hands-on is often used as a synonym to experiential, yet in the ID literature it refers to building something physical. Even though hands-on learning is nothing new in ID education, particularly in studio courses, handling materials is often addressed as an idea generation tool (Viswanathan & Linsey, 2010). However, hands-on learning has a further potential: When hands-on learning comes forward in studio courses in ID education, students tend to learn engineering-based knowledge more efficiently (Yavuzcan & Şahin, 2017). Tactile experience is both a self-expression tool and a learning style.

Reductionism and Holism

Independent of the preferred style, learning is the source of knowledge and knowledge of an individual is currently classified and measured by competencies. Schilling and Koetting (2010) mention that a competency-based approach is the fourth educational movement: Vocationalism (1), essentialism (2), social efficiency (3) and competency-based education (4). Competency is an interrelated set of attitudes, skills and knowledge (Government of Alberta, 2011), and a competency-based approach is the most up-to-date movement (Schilling & Koetting, 2010). Horváth's (2006) approach divides the competencies into two: Conventional reductionist (1) and innovative holistic (2). In reductionism, comprehending isolated elements is enough to analyse complex systems (Schilling & Koetting, 2010). Holism is the opposite. A system is a whole and elements should be examined by considering their relation to each other (Horváth, 2006). In ID, these elements are knowledge of mechanisms, materials, manufacturing, drawing, etcetera (Siegel, 2000). Horváth (2006), criticizes reductionism as being inefficient, while others accuse it of being epistemologically weak, educationally and philosophically inadequate and inappropriate (Brundrett, 2000). Even though reductionism is often not received well, measurability still helps it remain valid. Nonetheless, in the 2010s another stage of educational approach has begun. Despite being introduced in 1990 (Maurya & Ammoun, 2018), engineering design education benefited in the last decade from an approach known as CDIO. It stands for Conceive, Design, Implement and Operate. It is an active learning tool for the theory of technical systems and the theory of design methodology, besides being a holistic competency model (Bao, Liu, Lu, Xiang & Chen, 2014). In respect of its experiential and holistic structure, CDIO is assumedly what fits best to education of the theory of technical systems in ID programs. Nevertheless, best results can only be obtained by a complete or an extensive curriculum integration (Norinpel, Gonchigsumlaa, Tungalag & Purevdorj, 2018). This is already being implemented in some of the ID departments in the UK. However, as far as is known, there is no existing CDIO implementation in Turkey, in ID programs.

An Overall Criticism

Integration of technological development into design education is needed, and some universities have revised their curricula and their expected learning outcomes (Overbeeke, et al., 2004). However, the rest, and particularly in Turkey, maintain their conventional approaches.

Designers fail to use a common interdisciplinary language (Persson & Warell, 2003), particularly with engineers, which employers demand. The skill sets graduates have and what companies search for often do not match (Erkarslan, et al., 2011; Domermuth, 2009; Yang, et al., 2005; Kındı, 2007). Even though computer aided design skills and knowledge of mechanisms and manufacturing are vital, they disappointingly rise above all the vocational skills (Erkarslan, et al., 2011; Yang, et al., 2005; Siegel, 2000; Süel, 2006). Despite design education methodologists discrediting a reductionist approach, employers show strong resistance by preferring it. Besides, the mentioned skills of graduates are under the level which companies desire (Domermuth, 2009).

On the other hand, ID students often solve mechanical problems poorly (Bingham, et al., 2015) and ID graduates emphasize visually aesthetic innovation over any other creative solutions (Liu, Lee & Tsing, 2013). The conventional theoretical focus of engineering lectures is regarded as the reason for this tendency (Roozenburg, et al., 2008; Yavuzcan & Şahin, 2017).

Modern ID programs differ from the pedagogy of early Bauhaus. If not research-centred (Friedman, 2002), universities generally design a moderate curriculum, containing less hands-on learning sessions than the Bauhaus era. (Yang, et al., 2005; Zeng, 2017; Gropius, 1923). Innovative perspectives for hands-on learning in studio courses are suggested and applied by some researchers (Roozenburg, et al., 2008; Yavuzcan & Şahin, 2017; Bingham, et al., 2015). In Turkey, it is often discussed whether lecturers have comprehensive practical experience, and a lack of it is a great hindrance in experiential learning. Universities and researchers in the Far East put much emphasis on this issue (Bai & Sun, 2018; Zeng, 2017). On the other hand, universities, often lack modern facilities and equipment for offering an up-to-date experiential learning process (Zeng, 2017). According to Zeng, students' access to manufacturing tools and machinery supported by practical experience of lecturers increases the efficiency of ID education.

Supposedly, considering the curricula of the ID departments in Turkey, Turkish ID education appears to include inductive learning to support deductive learning conventionally. However, according to an unstructured observation in a previous assignment, a gap is suspected to exist between deductive and inductive learning. When students omit or ignore analysing mechanisms holistically, they propose superficial and failing designs. In this research, the ability of students to design mechanisms is focused on and a toolkit is designed hereby. However, the criticism can be broadened to all of the engineering-based courses in further studies.

Toolkit and Methodology of the Research

The toolkit is best described in comparison with existing practice. Contemporary ID education in Turkey is explained in Figure 1. The existing curriculum is nearly identical to Hubka and Eder's (1987) classification of design science. Thus, a version of it is used in the toolkit.

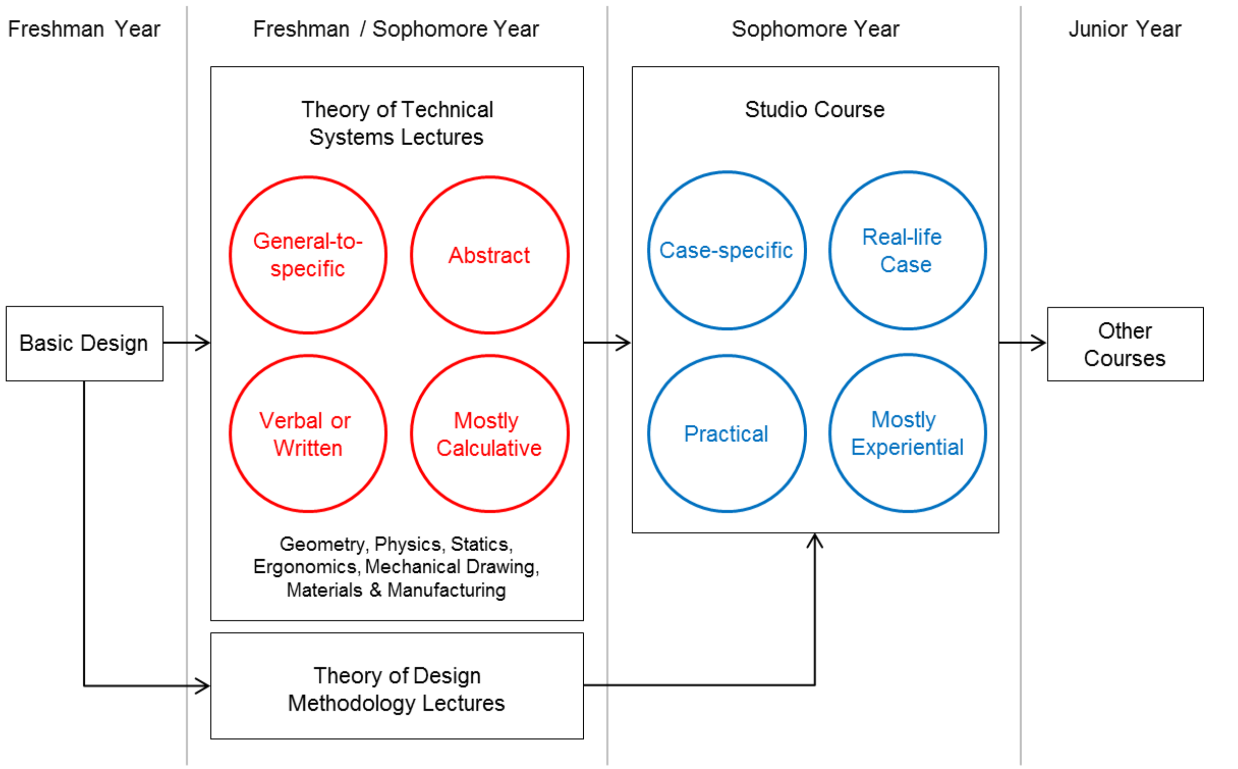

Figure 1. Contemporary ID education in Turkey

A freshman year in ID education is usually focused on basic design. However, students take lectures about the theory of technical systems and the theory of design methodology simultaneously. These lectures are usually general-to-specific, abstract, verbal or written, calculative and focused on reductionism. In the sophomore year students continue to participate in these lectures, beside studio courses. Studio courses are almost completely experiential, active, hands-on and require a totally holistic approach. Lectures on theory of technical systems are nearly the total opposite of the studio courses. The flow of theory to experiential learning is a typical two-staged deductive learning style.

The toolkit adds two phases between theory and experiential learning. Learning in the first stage is semi-deductive and experiential, but it needs a calculative approach. There is a case, yet it is abstract. Students are mostly active; however, they learn in a general-to-specific pattern. The second stage is semi-inductive. Unlike the first stage, an assignment is a real-life case and learning is in a specific-to-general pattern, while still holding a calculative design approach (Figure 2).

The toolkit benefits from a simplified classification of mechanisms: speed reduction (1), vector manipulation (2), timing (3) and reversing (4). In the first stage students research, design and prototype an abstract mechanical system. Designed objects should have only a little sense-making purpose and designs must be driven only by hand-power. In this way, students are not distracted from the engineering focus. In the second stage, students are asked to develop and present their designs about a certain product definition. Requirements of the assignment are including at least two of the mechanisms studied and electronic drives and sensors are not allowed.

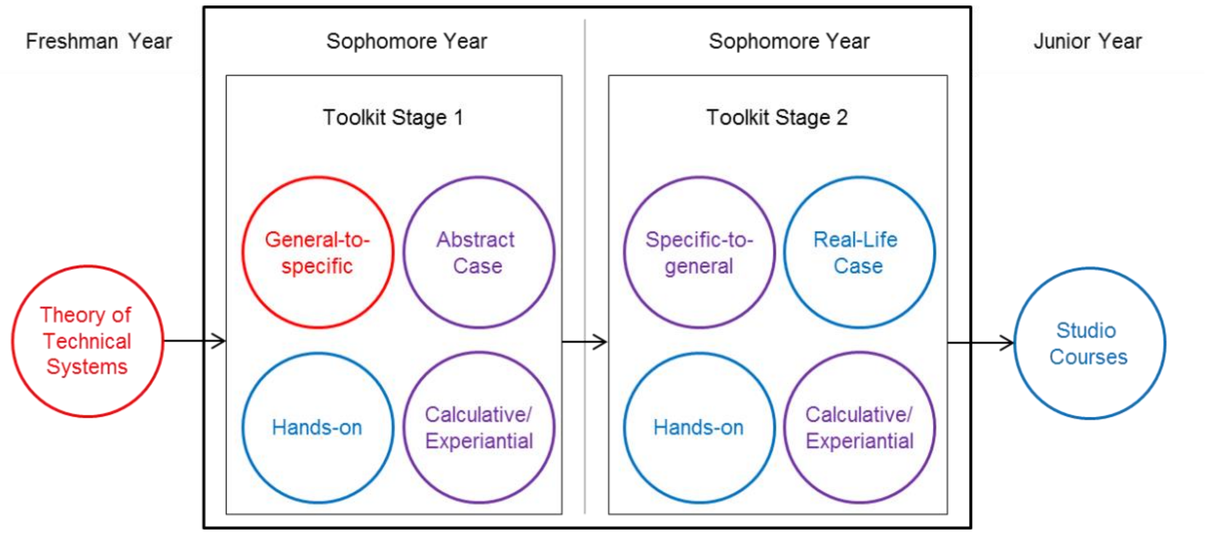

Figure 2. The toolkit

The purpose of the toolkit is to help students relearn theoretically gained engineering knowledge in the lectures on the theory of technical systems with an experiential and hands-on learning approach. The toolkit put emphasis on evaluating the competencies of the students holistically. Assessment of the students should be made considering this purpose; therefore,

the toolkit includes the slightly modifiable assessment guide below, which is answered by each instructor via a 5-points Likert scale:

1. Does the design meet the required mechanical functions?
2. Are the functions of the mechanisms consistently designed?
3. Does the student have comprehending knowledge of mechanisms?
4. Does the prototype fully operate?
5. Is the material selection adequate?
6. Is the structure appropriately designed?
7. Are the joints and beddings properly designed?
8. Is it ergonomic?
9. Is the design original?
10. Is the purpose of the design clear?

The toolkit suggests evaluating the students at the end of both phases through the above-mentioned guide. Final evaluation is an overall score while differences between the assessments show the efficiency of the toolkit.

Research Methodology

The aim of the research is to present a toolkit to increase learning efficiency of the theory of technical systems for ID students in Turkey, intending to provide a controlled transition from theoretical to experiential learning. The research question is, "does the toolkit make contribution to the teaching of theory of technical systems for the ID sophomore year students?".

The toolkit was applied to 36 students of the ID department of [anon] University. While it is non-probability sampling, the sample represents itself. One of the students left during course, thus, 35 participants were evaluated by the assessment guide of the toolkit. A paired-samples t test was preferred for statistical analysis of the assessments. In a paired-samples t test, measures repeat on the same subjects over a period and minimum of 30 samples are required (Zimmerman, 1997).

Students participated in a 5-point Likert scaled questionnaire. As well as that, they answered a 3-point semi closed-ended question. 31 students returned the questionnaire. Researchers used participant observation to triangulate the findings.

Findings of the Toolkit

The findings regarding the toolkit are presented in terms of participant observations, student questionnaire results and lecturers' assessments, respectively. Images of the selected prototypes are given in the following order: first stage outputs in the left, second in the right.

Participant Observations

In the first stage, P5 (participant 5) could build a merely working abstract toy. However, in the second stage P5 designed and prototyped a fully operating leaf sweeper, driven by its wheels while the product is being pushed. Considering that belts, pulleys, bedding and shafts are designed appropriately, P5 improved notably in the second stage (Figure 3).

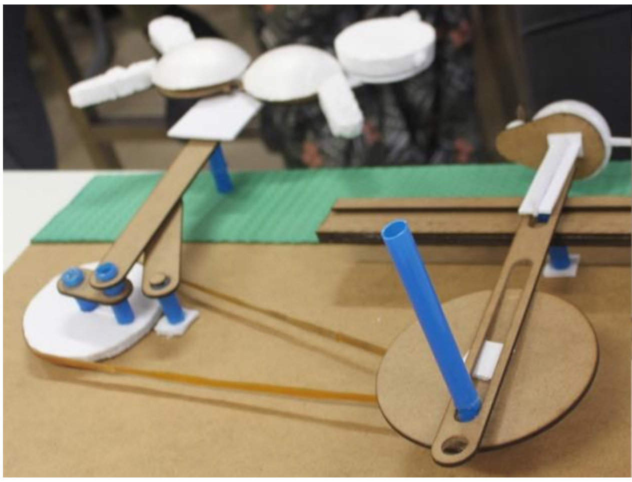
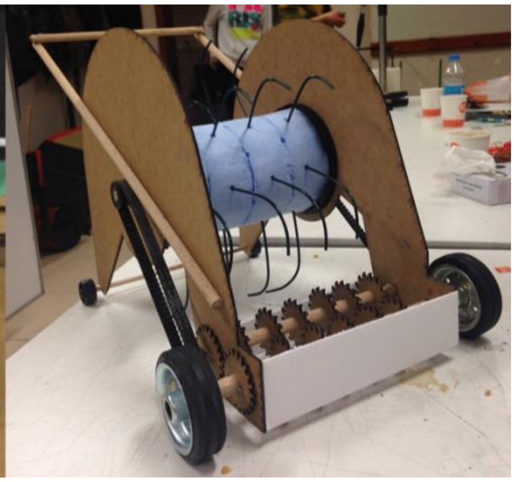

Figure 3. Toy and leaf sweeper (P5)

The first prototype of P8, a stamp tool, tended to tip over due to the weak design of joints. The chassis design and steel usage in the second design, a shredder, shows that the structural design approach of P8 is eminently changed (Figure 4).


Figure 4. Stamp tool and shredder (P8)

In Figure 5, P17's olive oil extractor design, on the right, is structurally more consistent compared to her first stage design, an abstract crane. And in Figure 6, P19's sowing machine design, on the right, is designed clearly in a more holistic approach, regarding the joints and bedding of the structural and the moving elements are designed more appropriately compared to her first stage design, a toy with a turning table. The mixer design of P27 (Figure 7), on the right, uses a planet gear which is fully operating. However, in the first stage, P27 designed a merely working, moving diorama. Thin and yielded shafts are visible on the left.

Figure 5. Crain and olive oil extractor (P17)

Figure 6. Toy and sowing machine (P19)

Figure 7. Moving diorama and mixer (P27)

In Figure 8, welded steel chassis, steel shafts and bearings are visible in P30's second stage design, a dust cleaner. However, the student lost her control over visual output due to outsourcing most of the elements.

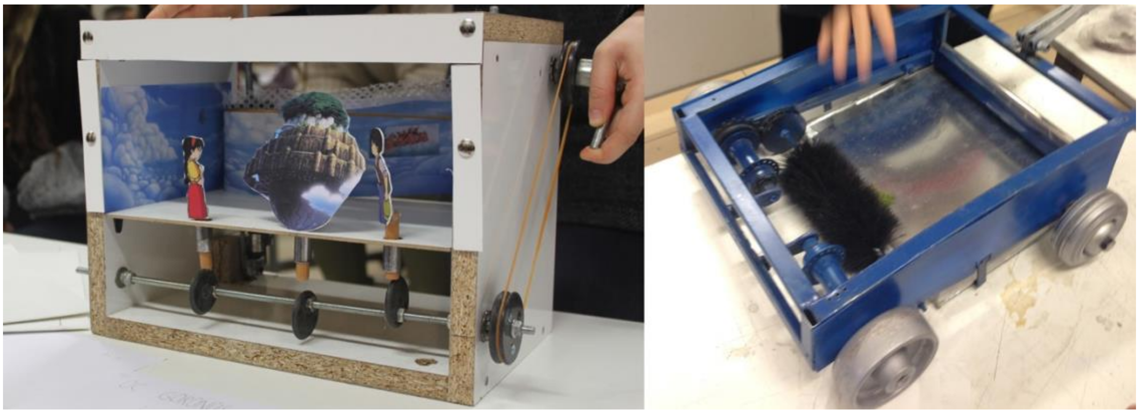

Figure 8. Moving diorama and dust cleaner (P30)

P36, produced a fully operating and reasonable prototype in the first stage, a short movie toy, (Figure 9). In the second stage, P36 designed a four-bar connection with customizable bar and pendulum lengths, which let the user to draw variety of patterns on walls. The second stage output of P36 was succeeded by seeking a function driven novelty, as well as designing proper details for manufacturing. The output can be shown as a good example in terms of the results of the toolkit.

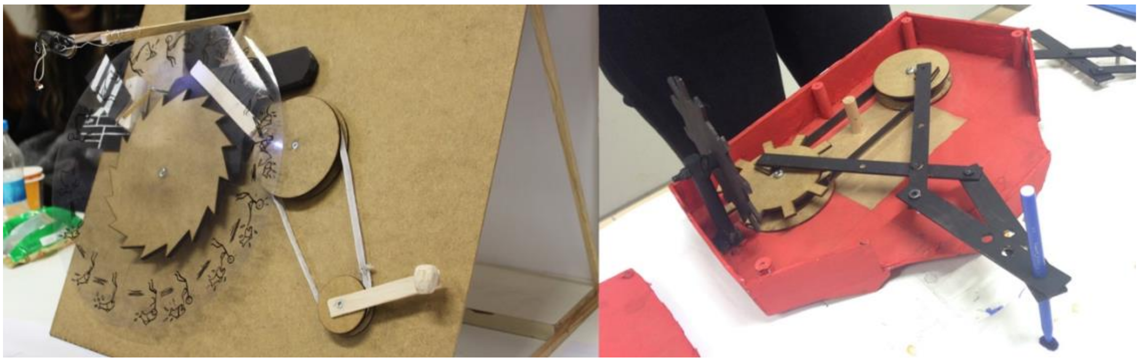

Figure 9. Short movie toy and drawing tool (P36)

Findings of the participant observation support that the toolkit can be useful to improve the cognition of the students of how mechanisms work and how they should be included. A notable number of students explored mechanical configurations as a tool for seeking novelty. However, most of the students were criticized during the juries about ill-designed ergonomics and visual aesthetics.

Students were not restricted to process specific materials when prototyping. However, they frequently outsourced laser cut medium density fibreboards. Because of the ID department having only a few machines, laser cutting of these boards can be outsourced from nearby facilities. Some of the students outsourced sheet metal cutting, bending and welding or milling of steel and aluminium. Only a few students benefited from 3d printing because of the long printing times needed to print numerous parts. Considering that it is more expensive and time-consuming to process metals and to 3d print, students may fail to revise and optimize their prototypes due to lack of time and financing. Most of the students tried to use simple tools to form cardboard and foam in the early stages. However, they have experienced that building a mechanical system requires higher precision than hand crafting can offer. Thus, lecturers

agreed that laser cutting of fibreboards is more beneficial where applicable. Thus, some of the students were advised to benefit from laser cutting accordingly.

Student Questionnaire

In the first two questions, students evaluated their progress of vocational knowledge in the theory of technical systems and theory of design methodology. Three-fourths of the students agreed or strongly agreed that the project helped them learn skills in both contexts. While 7% did not agree, 16% were neutral. The mean of the answers is 4,06 (Q1) and 4,00 (Q2).

In Q3, students were asked if the design project helped them develop design concepts. While 36% were neutral, 29% agreed and 19% strongly agreed to the statement. Almost half of the students answered positively, and the mean of the answers is 3,48.

In Q4, students were asked if the design project guided them through their novelty seeking. 74% of the students agreed or strongly agreed to the statement. 19% answered neutral and 7% did not agree. The mean of answers is 3,94.

Q5 aimed to evaluate the opinion of the students about the effect of a project having no mechanical restrictions on their innovative thinking. Findings show that 42% of the students strongly agreed to the statement. Agreed and strongly agreed answers analysed together, 81% of the students believed that constraints suppressed their novelty seeking. The mean of the answers is 4,16.

In Q6, the aim was to understand if the students were motivated by the toolkit. Findings are remarkable: 36% of the students agreed, 29% did not agree and 25% preferred neutral. The mean of the answers is 3,26. One-third of the students who were negatively affected should be taken into consideration.

In Q7, students were given a few optional statements and asked to choose which fit their opinion. Accordingly, prototyping and making it fully operating, ideating and drawing mechanisms are the most frequent problems that students faced. However, 84~88% of the participants believe that they strove to succeed (Figure 10). Only two students chose the open-ended option, and both believed that they strove to succeed while they faced with the below mentioned problems:

(1) “To understand what a mechanism is and what is the definition of it”
(2) “To understand the problem-solving technique”

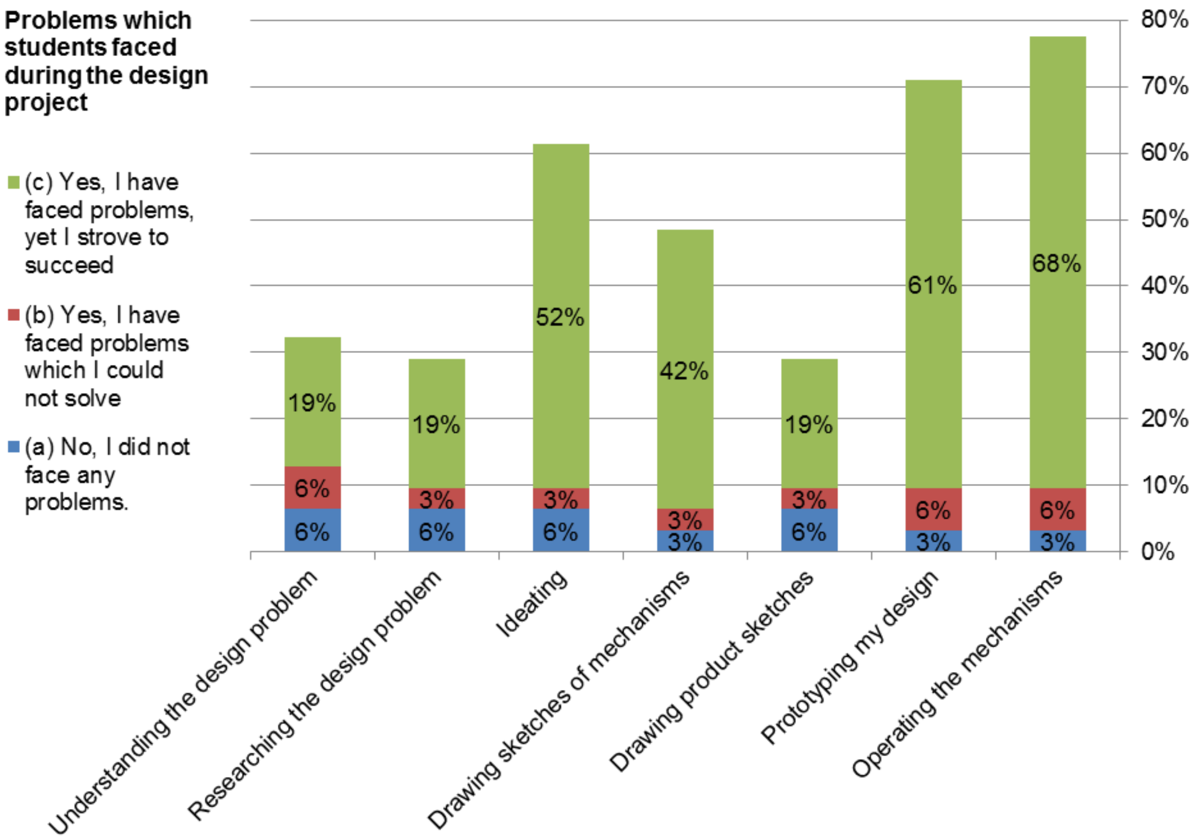

Figure 10. Results of Q7 in the student's questionnaire

In Q8 students were asked if the project helped them learn manufacturing knowledge. 55% of the students agreed, 23% answered neutral and 16% did not agree. Two of the students strongly agreed to the statement. The mean of the answers is 3,51. While some of the students processed steel, aluminium and wood which are common yet hard to process industrial materials, the rest of them used medium density fibreboard, cardboard and foam which are also common, yet easy to process by hand or to outsource, providing less learning opportunity.

In Q9, students were asked if the design project helped them learn mechanisms. The majority (84%) of the participants agreed or strongly agreed. The mean of the answers is 4,03. Considering the findings, the toolkit is evidently efficient in teaching mechanisms.

In Q10, students were asked if the design project helped them experience designing a real-world product. 52% of the students agreed or strongly agreed and 36% preferred neutral. The mean of the answers is 3,45.

In the final question Q11, the aim was to understand if the method helped students analyse and optimize their design proposals. 81% of the participants agreed or strongly agreed. Only one student disagreed and 16% preferred neutral. The mean of the answers is 4,10. The summary of all answers except Q7 is shown in Figure 11.

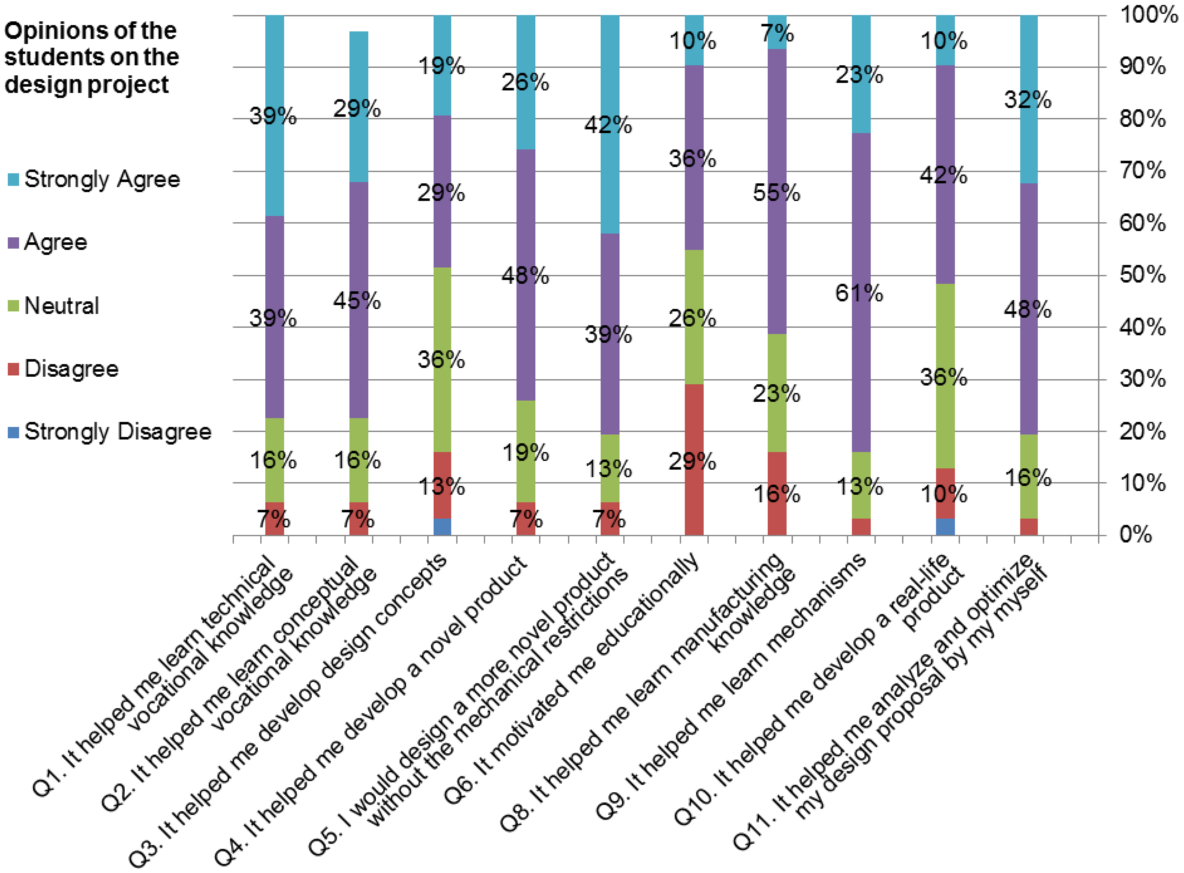

Figure 11. Results of the student's questionnaire

Assessments of the Lecturers

5 lecturers evaluated 35 students individually over 10 assessment criteria for each of the 2 mentioned stages. In total, 3,498 valid and 2 missing answers were analysed. In the second stage, the average of the student scores in each criterion increased between 8,5-20,8% when compared with the first stage. Students built structures (A6), bedding and joints (A7) with over 20% improvement. Students showed less than 10% progress between the two stages in meeting functional requirements (A1), obtaining comprehending knowledge of mechanisms (A3) and building fully operating prototypes (A4). Considering that students progressed at least 8,5% in all the criteria, the toolkit has been useful in the education of the theory of technical systems (Figure 12). 74% of the students progressed in the second stage, at least in half of the 10 criteria. On average, each student progressed in 7 assessment criteria. Notably 34% progressed in all the criteria, and only 9% showed no progress at all. For each assessment, 20~37% of the students got equal or worse scores with respect to the first stage. The average progress of assessments is 71%.

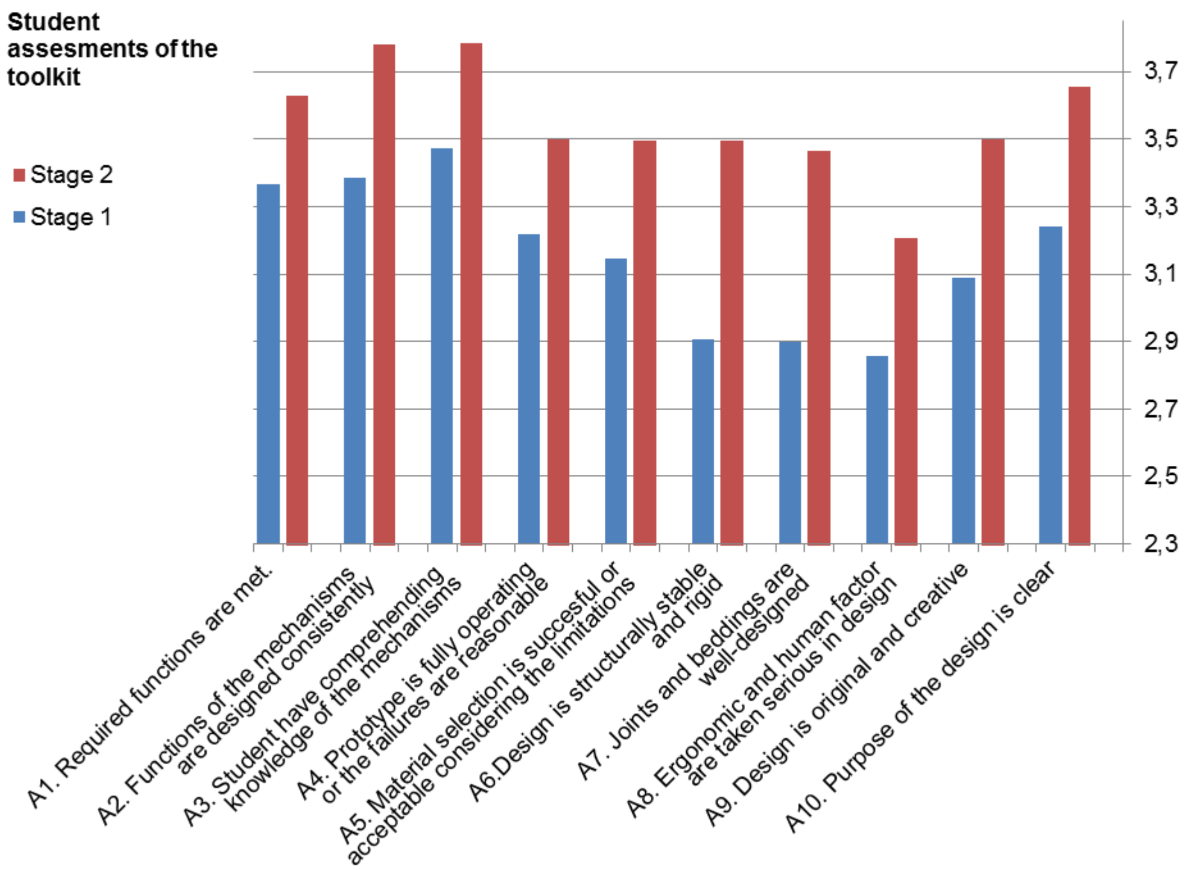

Figure 12. Lecturers' evaluation over 10 assessment criteria in both stages

The variation of each assessment criteria in both stages are validated in the 0,01 or 0,001 confidence intervals through a paired-samples t test (Table 1). However, sample size should be enhanced for providing a better idea about a larger population.

Table 1. Paired-samples t test results of the assessments

Paired-Samples t test			
Stage 1 compared to **Stage 2**	t	df	**Sig.-2 tailed (p)**
A1. Required functions are met.	-3,69	34	0,001
A2. Functions of the mechanisms are designed consistently.	-4,9	34	0,000
A3. Student have comprehending knowledge of the mechanisms.	-5,06	34	0,000
A4. Prototype is fully operating, or the failures are reasonable.	-3,14	34	0,003
A5. Material selection is successful or acceptable considering the limitations.	-3,31	34	0,002
A6. Design is structurally stable and rigid.	-5,09	34	0,000
A7. Joints and beddings are well-designed.	-6,03	34	0,000
A8. Ergonomic and human factor are taken serious in design.	-3,72	34	0,001

A9. Design is original and creative.	-3,52	34	0,001
A10. Purpose of the design is clear.	-3,84	34	0,001

Consequently, while the application of the toolkit shows significant signs of progress in learning of the theory of technical systems, it is also seen that some further revisions would stimulate an increase in the motivation of students.

Discussion: Validity of the Toolkit

It was considered by the staff that hands-on learning is influential when teaching the theory of technical systems. There has been obvious progress, yet designs were overwhelmingly focused on developing a fully operating prototype, often ignoring the visual aesthetics of designed products and, in some cases, the ergonomics. Although the criticism is substantial, the progress in learning of the theory of the technical systems is worthy. On the other hand, aesthetics in pedagogy should not be considered only for the visual quality of products. It is any kind of sense perception (Faste, 1995) during learning. In fact, even though art lost its priority in ID education (Findeli & Benton, 1991), aesthetic approaches are still implemented in ID pedagogy by benefiting hands-on and experiential learning methods (Düzenli, et al., 2018; Belgin Dikmen, 2011). However, it is a question of debate if these implementations are sufficient or conscious (Roozenburg, et al., 2008; Bingham, et al., 2015; Yavuzcan & Şahin, 2017). Consequently, it is understood that there is room for improvement. Implementation of the toolkit displays that teaching of mechanical engineering knowledge is one of the topics of this debate. Benefits of the toolkit are mostly significant on the learning of mechanisms and structures among all the subjects of the theory of technical systems. Neither observations nor student questionnaire indicates a conflict with the findings of the toolkit. Thus, considering the arguments of companies that graduates particularly lack the knowledge of mechanical systems (Domermuth, 2009), the proposed toolkit can be beneficial. On the other hand, students criticized the mechanical restrictions of the toolkit as an obstacle for seeking novelty. Nevertheless, in the overall review, they found the application helpful. Briefly, the method is useful for ideating in a structurally and mechanically reasonable way, embracing a “knowing how” motto (Sheppard, et al., 2006), yet restrictions may be limiting. While one-third of the students disagreed that the project motivated them educationally, another one-third agreed to the statement. Some students may not be interested in mechanical designs. Heterogeneity on interests is foreseeable, and lack of interest can demotivate the students. Considering that the toolkit is focused more on knowledge of the theory of technical systems and hands-on learning, it may be expected that some of the aspects of an ordinary design assignment will be missing. These missing aspects can be compensated by other assignments, while students’ lack of motivation is a matter of concern. Moreover, material restrictions are also necessary in the further applications for learning manufacturing knowledge more intensively, despite restrictions being demotivational. It can be assumed that the accessibility of tools and machinery is substantial (Zeng, 2017), as the toolkit benefits hands-on approaches.

Conclusion

A long-known debate exists behind teaching the theory of technical systems to ID students. Companies often request engineering-oriented knowledge from the graduates (Erkarslan, et al., 2011; Kındı, 2007), yet researchers heavily discredit the reductionism of the employers (Horváth, 2006). Nevertheless, considering that graduates severely lack engineering skills

(Domermuth, 2009), education of the theory of technical systems should be a matter of concern. Curricula of ID schools in Turkey already include both lectures on the theory of technical systems and theory of design methodology as well as experiential learning in studio courses that are based on inductive and deductive learning. Considering that these lectures are prior to studio courses in Turkey, teaching the related engineering knowledge to ID students is clearly a deductive learning approach.

The applied toolkit shows remarkable signs of progress in comprehending technical systems. Findings validate the research question: The toolkit contributes to the comprehension of the theory of technical systems through building a structured transition between theoretical and experiential approaches. Thus, the toolkit can be beneficial in CDIO approaches, considering that experiential learning and holism are the bases of CDIO. Further amendments of the toolkit should consider the criticism that restrictions may be demotivational, limiting the search of novelty and decreasing visual quality of the design proposals. Restrictions could be narrowed moderately; however it should be noted that they have a worthy role in the hands-on learning approach of the toolkit.

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Tracing back materialized ideas to embodied and verbal dialogues: Analyzing documents and videofootage of crafts and design lessons

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Abstract
This article discusses a case study combining the qualitative analysis of documents and videofootage. The data was collected during a short collaborative task within an ideation phase with9-10 year old pupils customizing a store-bought t-shirt. The combination of video and document analysis allows tracing back the emergence of some of the kernel ideas visible in prototypes and final designs. The analysis also shows that the pupils in the case study have developed a pool of ideas during several collaborative phases that they could draw back on for their final designs. The close observation of both verbal and embodied dialogue in video analysis shows that the individual, simultaneous and conjoint handling of materials in an exploratory way -– touching and examining, arranging and rearranging – as well as the verbal dialogue taking place during the design process plays an important role within the ideation phase in Crafts and Design lessons. Thus, the article supports previous studies in this area. This small-scale case study can also be taken as an example for how to practice studying subject-specific learning and teaching for students in teacher education with documents and videofootage providing a rich resource. Additional materials available on an online-portal as of June 2020 serve as a starting point for this endeavor.

Keywords
Collaborative Design, Video Analysis, Document Analysis, Ideation, Embodied Dialogue, Primary Design Education

Introduction
The aim of the case study in this article is to examine aspects of verbal and embodied dialogue of pupils in an ideation phase and link them to collaboratively developed kernel ideas made visible and tangible in prototypes and in the final design of the product. The study is based on the working hypothesis that providing a rich variety of readily available and well organized materials for designing prototypes can inspire both embodied and verbal dialogue among pupils while handling materials exploratively and help them generate a shared pool of ideas that they can draw upon when designing their individual products. The following analysis aims at reinforcing this approach by taking a close look at selected data of 9-10 year old pupils – 4th grade in Switzerland – customizing a store-bought t-shirt on a microlevel.

The study is based on data collected for the project “Developing Textile Products Cooperatively” (DTPC) (Eichelberger & Huber Nievergelt 2020a; Eichelberger & Huber Nievergelt 2020b). The project was part of the larger endeavor “Competence-oriented, subject-specific development of classroom teaching” (KfUE) that included a range of other subjects besides TTG (Adamina et al. 2020). The main goal was to develop, put into practice and document teaching units to generate materials for a web-based, password-protected portal

“KfUE” (Adamina et al. 2020) to be used in teachers education to further students’ professional knowledge (Harms & Riese 2018; Frommelt, Fürrer Auf der Maur, Biaggi, Hugener & Krammer 2016).

Based on the paradgims of design-based research (Anderson & Shattuk 2012; Prediger, Gravemeijer & Confrey 2015; The Design-Based Research Collective 2003), DTPC stressed the close collaboration of teachers and researchers in the design of teaching units. However, the goal was neither the perfection of the lessons for reproduction nor the development of universal design principles for learning units within the subject, but rather to focus on the challenges and opportunities of an everyday, authentic, sometimes messy school practice. The data-pool deriving from DTCP forms a rich “ethnographic collage” (Friebertshäuser, Richter & Boller 2010), comprising of videofootage, photographs of prototypes, final products, learning journals and portfolios, teaching materials and lesson plans as well as field notes taken while observing the recorded lessons, making it possible to combine analysis of documents and videofootage, similar in part to the proceedings in Lahti, Seitamaa-Hakkarainen, et al. (2016).

Handling materials as a subject specific aspect of dialogic learning

Embodied and verbal dialogues between pupils and the materials at hand during the design process, especially in ideation phases, are crucial for the subject design and technology/crafts and design/sloyd, or “Textiles und Technisches Gestalten” (TTG) as the subject is called in Switzerland – roughly translated as “Textile and Technical Crafts and Design”. Studies show that embodied practices play an important role within a subject specific learning process (Lahti, Kangas, Koponen & Seitamaa-Hakkarainen 2016; Koskinen, Seitamaa-Hakkarainen & Hakkarainen 2015; Lahti, Seitamaa-Hakkarainen, Kangas, Härkki & Hakkarainen 2016; Mehto, Riikonen, Hakkarainen, Kangas, Seitamaa-Hakkarainen 2020). The mentioned authors describe manipulating materials as a means of externalizing ideas, thus also providing a starting point for verbal dialogue (Yliverronen, Marjanen & Seitamaa-Hakkarainen 2018; Yrjönsuuri, Kangas, Hakkarainen & Seitamaa-Hakkarainen 2019). Closely related to this take is a so-called “trialogic” approach by Hakkarainen, Seitamaa-Hakkarainen, Paavola & Kangas (2013), stressing the importance of handling materials in collaborative learning while developing design ideas and solutions. The studies mentioned repeatedly state that despite the high relevance of these issues, they are not yet examined thoroughly and in detail so far. This article tries to help filling part of this gap by asking what connections can be drawn between the visible results of the pupils’ design processes (prototypes and final products) and the verbal and embodied dialogue between pupils and materials in a phase of collaborative ideation.

In the context of our project DTPC, it also seems crucial to heighten the awareness in teacher education regarding these issues. This is why dialogic learning was one of the main issues in DTPC. Furthermore, the project focused on collaborative and process-oriented learning aiming at changing a current practice often showing a strong emphasis on manual and technical skills and on the execution of products (Eichelberger 2014; Huber Nievergelt 2015; Huber Nievergelt 2017; Kimbell & Stables 2007). In contrast to that, the current curriculum for TTG for most of the swiss cantons stresses dialogic, collaborative and process-oriented approaches (Deutschschweizer Erziehungsdirektoren-Konferenz 2016; Deutschschweizer Konferenz der Erziehungsdirektoren 2020).

Regarding dialogic learning, we first based the development of the teaching units in DTPC on an existing model that emphasizes the importance of authentic dialogue between teachers and pupils (Ruf, Keller & Winter 2008). However, this and other concepts and studies within the paradigm of dialogic learning focus mainly on language (Wells 1999; Resnick, Asterhan, Clarke & Schantz 2018; Fox-Turnbull 2016), which is only part of the dialogue relevant in TTG, as has been shown in the introductory paragraphs. Therefore, we suggested an extension of language-based models considering dialogues with materials, for the pupils as well as for the teachers (Eichelberger & Huber Nievergelt 2020b). The dialogue with materials is viewed both on an individual and on a collaborative level, which means that embodied interaction is of essence when handling materials individually as well as conjointly. We understand the term collaborative according to O'Donnell and Hmelo-Silver (2013) as an activity that fosters "mutual influence and equality of participation".

The statements show that our understanding of dialogue is closely related to studies on embodied aspects of teaching and learning crafts and design (Lahti, Kangas, et al. 2016; Riikonen, Seitamaa-Hakkarainen & Hakkarainen 2020; Yrjönsuuri et al. 2018; Huotilainen, Rankanen, Groth, Seitamaa-Hakkarainen & Mäkelä 2018). Huotilainen, Rankanen, Groth, Seitamaa-Hakkarainen & Mäkelä (2018) for example mention "embodied cognition" (4) as a basic form of learning that can be achieved in arts and crafts specifically. The same authors also emphasize the importance of providing different kinds of materials to give "a rich variety of somatosensory stimulation" (4-5) which has proven to be an essential factor in all of the teaching units. Providing a variety of inspiring materials to encourage a dialogue of the pupils with materials is further supported by findings of Lahti, Kangas, et al. (2016) and Kangas & Seitamaa-Hakkarainen (2016), the latter mentioning the importance of modelling materials for younger children (8). Other studies support these findings and show that there are different possible ways for pupils to deal with materials (Wyss 2018; Marti, Bühler & Brunner 2010; Gaus-Hegner 2004).

Last but not least, the inclusion of both verbal and embodied dialogue while handling materials is closely connected to the concept of design processes as a constant shift between thinking and doing, as Kimbell & Stables state in several publications (Kimbell & Stables 2007; Technology Education Research Unit (TERU) et al. 2004; Kimbell 2008). The same authors also stress that the making of a final product is not necessarily the most important part for the subject at hand, but the ideation phase and therein the modeling with different materials has value in itself (Kimbell & Stables 2007).

Situation and Task of Analyzed Data

The situation examined in this article can be described as follows: A group of eight 9-10 year old pupils – names altered to provide anonymity – were given the task of personalizing a store-bought t-shirt in a teaching unit encompassing 8 weeks, each week comprising of 2 lessons. According to Heuflers functions of a product (Heufler 2012), the design task comprised of the following constraints: Regarding the aesthetic function of the product, the t-shirt must signal a visible and/or haptic customization that makes the plain, store-bought product unique; regarding its practical function, the t-shirt had to be wearable and washable. During the ideation phase, the pupils repeatedly worked in small teams to develop a pool of ideas regarding the use and alteration of colors, shapes and material surfaces to draw upon for their individual designs, thus representing phases of "creating conceptual and visual design ideas"

and “experimenting and testing design ideas” according to the model “learning by collaborative design” (Hakkarainen et al. 2013, 61).

The task for the sequence analyzed took part during the fourth week. The pupils had already worked on the themes of color and form previously. Now, the teacher had arranged three tables with learning stations to explore different possibilities for altering the surface of a t-shirt with colors or added material by 1) printing with stamps, 2) mask and stencil printing and 3) application of various materials. The pupils were to associate and use materials freely, not yet hampered by the final outcome of the product. As an additional possibility, the teacher had also provided old t-shirts whose surfaces could be altered by cutting into them. However, this possibility lead to some difficulties in classroom management and had no impact on the final design of the products, it is therefore not further examined in this article. The video camera was focused on learning station number 3) since we expected the dialogue with the provided array of fabrics, yarns, ribbons, buttons, beads, and sequins to be promising regarding the handling of materials.

The pupils were working in three teams – called *Mustache*, *Sparkle* and *Smile*, after the results of their prototypes – and were encouraged, but not strictly obligated to cooperate, sometimes leading to the splitting of teams (see table 1). The teams worked at the task one after the other, thus picking up where the previous team had left off. As the last team, team *Smile* showed signs of declining concentration resulting in a high amount of non-task-related activity, possibly furthered by a difficult social setting (O’Donnell & Hmelo-Silver 2013, 5). After the activities at the learning stations, the whole group exchanged experiences in a discussion led by the teacher and all pupils had to sketch a draft and jot down what techniques they intended to use as well as what materials they needed for the elaboration of their design in the following weeks.

Table 1: Overview of teams

	Team Mustache	**Team Sparkle**	**Team Smile**
Time on task in minutes and seconds, starting and ending with teachers’ instructions to start and finish the task	11:08	15:16	15:35
Members and organizing of teams	Alan, Bianca, Cyril (Alan working only at cutting a t-shirt, activities are not further analyzed)	Dario, Elena	Fiona, Gerard, Henry (Fiona working mostly individually, activities are not further analyzed)

Method

In a first step, photographs of prototypes and final products were examined using basic elements of thematic content analysis for documents, in which a detailed description led to the definition of visual themes and, in case of the final products, a typology could be constructed (Kuckartz & Rädiker 2019b). In a second step, videoanalysis served as a tool for both embodied and verbal dialogue (Rauin, Herrle & Engartner 2016). The videoclips originate from one of three cameras used in the project DTPC, reacting flexibly in order to focus on emerging collaborative processes in small groups – the other two being a static overview camera and a dynamic camera following the actions of the teacher. Despite a sometimes slightly changing angle on the pupils’ activities and short interruptions of visibility, the videoclips at hand

constitute a rich source for analysis. Additional audio feed has made the translation of the verbal dialogue possible.

Regarding the selection of outtakes from the footage for the whole project DTPC, we followed qualitative-reconstructive proceedings suggested in Herrle & Dinkelaker (2018) in order to cope with the huge amount of material. The selected videofootage for this article has been coded in the application MAXQDA (Kuckartz & Rädiker 2019a). The embodied dialogue handling materials exploratively and the verbal dialogue have been examined from two perspectives: 1) The transcripts and the actions visible in the videofootage were scanned for connections to motifs and material characteristics of the prototypes and final designs. 2) Sequences where pupils were feeling materials or testing arrangements of materials with both focused gaze and touch were coded as "handling materials exploratively" in the videofootage, thus marking relevant embodied dialogue for the study. Sequences in which pupils are handling materials goal-oriented in the context of the task at hand – cutting with scissors, fixing materials with pins and sewing, opening and closing containers, preparing or putting away materials before or after work – have been excluded, as well as not-on-task activities. It has to be stressed that it is not the goal of this article to define the activity of "handling material exploratively" ontologically – the codes are specifically referring to the context of the task at hand.

In some of the sequences coded as "handling materials exploratively", the actions of the two pupils forming a team overlap, which means they are performing these actions simultaneously. These overlapping sequences proved to be especially interesting, since the simultaneousness sometimes led to collaborative actions. Thus, these sequences were analyzed regarding their frequency and the point in time of occurrence as well as regarding their contents by paraphrasing the occurring embodied and verbal dialogue. Interventions by the teacher – visible in the frame, talking and/or handling materials – have been tagged but are not further examined. Actions shorter than 5 seconds as well as interruptions of continuous actions or of visibility shorter than 5 seconds were not taken into account so as not to fragment actions into too small units and to break the narrative cohesion of the activities. Invisible actions longer than 5 seconds were marked as such and not taken into account, unless they could clearly be defined according to their context.

While the first perspective mentioned has been coded individually by the author, since assignment to motifs is clearly visible, the coding for the second perspective mentioned in the previous paragraph has been tested, discussed and optimized in two rounds for one of the teams, to improve intersubjective reliability. However, it has to be stressed that the data is not standardized and the definition of the codes can only be understood as an approximation of intersubjective intelligibility in a qualitative-reconstructive methodological sense.

Document Analysis: Prototypes and final products

The ideation phase described in the paragraph regarding situation and task resulted in 4 different designs (table 2). Regarding the aspect of shape as a design element, all results show a smiling face and round-edged rectangles symbolizing eyes. While teams *Mustache* and *Sparkle* arranged the rectangles vertically, team *Smile* used them horizontally. The face as a motif had started with the activities of team *Mustache* and was further developed by all groups. All faces have small noses, one face contains a mustache, as the team name suggests. Team *Sparkle* complemented the face with a rectangular shape covering the lower two thirds of the t-shirt,

sprinkled with a variety of small forms. This part forms the only non-representational part of all the results – team *Smile* shows only rudiments of scattered small forms.

Table 2: Result of ideation phase with materials

Team Mustache	Team Sparkle	Team Smile
 Bianca, Cyrill	 Dario, Elena	  Left: Fiona, right: Gerard, Henry

Regarding materials and surface as a design element, the eyes all consist of denim patches, the pupils inside them are made of buttons, beads and bead-like parts or fabric swatches, the eyebrows (team *Mustache* and *Sparkle* only) of furry ribbons, also the mustache. The noses consist of buttons, beads or sequins, the mouths of fabric swatches, wadding, ribbons or buttons. The non-representational rectangle of team *Sparkle* is made of dark fabric, sprinkled with a variety of sequins and beads and covered with blue net lace in a first version, in a second version there were more sequins and beads added on top of the blue net lace. Regarding color, the prevailing use of contrasting effects of dark or blazing colors on a white base are remarkable. A striking contrast can also be observed in the glittering scattered small shapes on the dark rectangular base in team *Sparkle*.

Regarding the final designs of the t-shirts, five types can be distinguished, three of them using a face or parts of it as a main motif (table 3). The aspect of contrasting colors is striking in all of the t-shirt designs. A first group of pupils, typed as “Big eyes”, put white eyes in the upper third, chose white and red pupils, outstanding eyebrows in turquoise fake fur, combining techniques of stencil printing and application. Parts of fake fur can also be detected in the shirt of Bianca in the group “Faces and blobs”. A second group of pupils, “Devils”, used heads with devil-like horns or ears, situated slightly below the center, with bright red pupils, combining techniques of stencil printing and stamping. A third group, “Faces and blobs”, placed elements of a face within an array of multicolored blob-like motifs scattered on the whole surface of the t-shirt. The types “Scattered blobs” and “Stars” do not use faces. Both show scattered motifs, either blob-like like the ones surrounding the face-elements in “Faces and blobs” or stars and dots. Cyrill in “Stars” combines these elements with an individual motif of geometric blocks that he had developed during a former ideation phase and complements it with a comets’ tail.

Table 3: Types of final designs of t-shirts

Big Eyes	Devils	Faces and Blobs	Scattered Blobs	Stars
 Dario	 Alan	 Bianca	 Elena	 Cyrill
 Gerard	 Henry	 Fiona		

Video Analysis I: Connections of Dialogues to Prototypes and Final Designs

The analysis of selected elements of verbal and embodied dialogue regarding motifs and characteristics of materials shows connections to prototypes and final designs described above. The transcripts show that all the main elements of motifs occurring in the final designs were being talked about in the ideation process (table 4).

Table 4: Verbal dialogues related to motifs in prototypes and final designs in order of observed frequency in the transcript, overall frequency below 5% with the exceptions mentioned

Team Mustache	Team Sparkle	Team Smile
☐ Furry materials ☐ Eyebrows ☐ Eyes ☐ Mouth ☐ Smiley-face ☐ Nose (mentioned, but not identifiable in prototypes and final designs: ninja, sleeping person, ribbon, clown)	☐ Shiny materials (7%) ☐ Stars ☐ Mouth ☐ “mess” ☐ Nose ☐ Eyes ☐ smiley-face ☐ eyebrows (mentioned, but not identifiable in prototypes and final designs: O-shape)	☐ Mouth (7%) ☐ Mustache ☐ Eyes ☐ Pupil ☐ Devils (mentioned, but not identifiable in prototypes and final designs: pattern, spear, sheriff, person, shirt)

As a main theme, faces or elements thereof occur in the verbal dialogues of all three teams, team *Mustache* and team *Sparkle* additionally talk about characteristics of materials. A remarkable incident can be identified within the verbal dialogue of team *Smile*, when Gerard exclaims “Look, we are devils!” while cutting t-shirts, and a little later on, Henry states “We are making a sheriff, with red eyes!” when placing beads as pupils. Alan, who was not part of this team, seems to have drawn upon these motifs from the common pool of ideas, since his final

design belongs to the type of “Devils”, together with Henry’s. On the whole, it is remarkable that in all teams, motifs are being discussed that are visible neither in prototypes nor products, thus indicating that the design pool generated in the ideation phase encompasses the used solutions.

A closer look at the embodied dialogue also shows connections to motifs and materials used in the final designs (table 5). Two main themes can be observed: Team *Sparkle* shows an intense engagement in creating what they sometimes called a “mess”, scattering an array of small, often shiny objects on the area of the dark rectangle on their white t-shirt. This embodied dialogue amounts to almost half of the total time and encompasses long stretches of activities, in which Elena was repeatedly talking about shiny materials, while Dario was more concerned with handling these materials, especially with scattering them on the whole surface with distinct movements. These distinct movements seemed to mark these sequences intersubjectively as explorative handling. The scattered elements in the design types “Faces and Blobs”, “Scattered Blobs” and “Stars” can be interpreted as traces of these activities. Furthermore, the inclusion of glitter paint in the final products by Bianca and Elena could be argued to emulate the shimmering effect of the prototype of team *Sparkle*, without the time-consuming effort of attaching sequins and beads to the t-shirt. It has to be noted that during the process described above, Elena was working more at the margins of the t-shirt and was sometimes being pushed aside by Dario, who took up a more central space at the table.

Table 5: Embodied dialogue handling materials by either one or both members of a team related to motifs in prototypes and final designs in percent of total time of videofootage

Team Mustache	Team Sparkle	Team Smile
Eyebrows (11%) Mouth (8%) Mustache (8%) eyes and mouth (4%) (assumed, partly invisible)	“mess” (49%) Mouth (7%) eyes and eyebrows (2%) nose (1%)	eyes and mouth (35%) (assumed, partly invisible)

The second motif taken up was the face as a whole or of certain features of it that has been taken up by all three teams. The design types “Big Eyes”, “Devils”, and “Faces and Blobs” can thus be traced to verbal as well as embodied dialogue. Furthermore, in connection to the outstanding eyebrows in the type “Big Eyes” and in Bianca’s product of the type “Faces and Blobs”, the haptic fascination with furry materials that has been discussed in Team *Mustache* is of interest. For this team, eyebrows, mouth and mustache as single elements were especially relevant and the engagement with them was clearly discernible within the activities. For team *Smile*, the embodied dialogue regarding motifs is only partly visible due to their moving around and due to repeated interventions by the teacher. From the context and their verbal dialogue, it can be assumed that they were mainly concerned with eyes and mouth.

Video Analysis II: Embodied and Verbal Dialogue while Handling Materials Exploratively

To gain insight into the phases of the embodied dialogue while handling of materials exploratively, an approximate quantification provides interesting results (table 6). Individual and simultaneous explorative handling occurred in the activities of every pupil and every team. The lengths of the single simultaneous phases range from 5 or 8 seconds to around 40 seconds,

combined, they are covering roughly one quarter of the whole time for team *Mustache* and *Sparkle*, team *Sparkle* showing a more scattered distribution, and around one tenth for team *Smile*. Within these phases there are tendencies to conjoint explorative handling when the pupils were focusing on the same materials or on the same area of the t-shirt. However, an exact definition has been difficult to achieve and therefore these phases have not been quantified.

Table 6: Overview of explorative activities of pupils, in approximate percentage of the whole time

	Team Mustache	**Team Sparkle**	**Team Smile**
Individual explorative handling of materials	Bianca 33 % (of which 3 % assumed only because of invisibility) Cyril 65 % (of which 3 % assumed only because of invisibility)	Dario 50 % Elena 39 %	Gerard 16 % (of which 2 % assumed only because of invisibility) Henry 37 % (of which 3 % assumed only because of invisibility)
Simultaneous explorative handling of materials	24 % (6 % with teacher present) □ 7 phases □ duration 5 to 38 sec. □ focused verbal dialogue in phases 1, 6, 7 (3 of 7) □ tendency for conjoint activities in phase 6, 7 (2 of 7)	24 % (3 % with teacher present) □ 16 phases □ duration 5 to 40 sec. □ focused verbal dialogue in all phases □ tendency for conjoint activities in phases 4, 5, 7, 8, 9, 10, 14, 16 (8 of 16)	11 % (6 % with teacher present) □ 4 phases □ duration 8 to 44 sec. □ focused verbal dialogue in phase 1, 4 (2 of 4) □ Tendency for conjoint activities in phases 1, 3, 4 (3 of 4)
Interventions of the teacher	35%	15%	39%

The percentage of time for individual explorative handling differs from 16% (Gerard) to 65% (Cyril). Being a member of team *Smile*, whose difficulties have been mentioned before, Gerard seemed to have been sidetracked with off-task activities most of the time. It can also be observed that in team *Smile*, roughly half of the simultaneous explorative activities were taking place when the teacher was present, leading to the assumption that her help was necessary to concentrate on task. Three pupils show a percentage that amounts to roughly one third of the whole time. Bianca (33%) of team *Mustache* acted exploratively mostly during the first half, arranging and rearranging motifs on the t-shirt, and performed more goal-oriented activities later on, fixing parts with pins or sewing. Elena (39%) of team *Sparkle* shows a similar pattern. Unlike Bianca and Elena, Henry (37%) of team *Smile* spent the rest of the time rather with non-task-related than with goal-oriented activities. It is interesting to see that also Fiona's activities, that are not discussed in this article, since she worked mainly on her own, show a similar pattern to Bianca and Elena. However, there is not enough data to draw gender-related conclusions. The highest amount of time handling materials exploratively can be found in the activities of Dario (50%) and Cyril (65%). Whereas Cyril was more inclined to exploring different materials without arranging them, Dario was concentrating on arranging materials on the t-shirt, often using very specific movements scattering small materials and sometimes pushing Elena aside, as has been mentioned before.

As a last aspect, a closer look at the verbal dialogue during the mentioned phases shows that only team *Sparkle's* dialogue was mostly task-related, whereas team *Mustache* and *Smile* often talked about non-task-related issues. It is interesting to consider that the latter were the teams

with three members each, both splitting up into a group of two and one individually working pupil. Furthermore, team *Sparkle* had the possible advantage of getting to the task in the middle of the whole lesson, already attuned to it but not yet exhausted.

Conclusion

The analysis of embodied and verbal dialogue centered around the explorative handling of materials shows that the materials provided by the teacher offered the opportunity for all pupils to explore individually as well as conjointly. The ideation phase generated a pool of ideas for the final designs of all pupils, even if not everyone was similarly involved in it. In this regard, it is remarkable that the teams working together in the ideation phase do not correspond with the types of the final designs. It can be assumed that the constant dialogue between pupils in the teams but also in the following exchanges within the whole group has led to closely related, yet individual design solutions and some kernel ideas can be traced back to the analyzed part of the ideation phase (Lahti, Seitamaa-Hakkarainen, et al. 2016). Interestingly, the motif of the face or parts of it has emerged in the very beginning of the ideation process and prevailed until the end of it. One of the reasons might be the idea of the first group of pupils to interpret the furry materials as eyebrows and the fabric patches as eyes which seemed to be of interest for the other two groups, too.

In regard to drafting a design task between openness and necessary constraints, it could have been helpful for the pupils to have a guiding theme for motifs to focus on, on the other hand it was interesting to see which motifs the pupils came up with themselves. Interestingly, the teachers' interventions in the design process of the pupils who were focusing closely on the task (Bianca, Cyril, Dario, Elena, Fiona) did not seem to make a substantial difference for their development of ideas, albeit sharpening their own ideas in differentiation to the teachers' suggestions. On the other hand, for the pupils who were mainly cutting t-shirts, thus following a path that was not taken up in the final designs (Alan, Gerard, Henry), the interventions by the teacher helped to focus on the task and develop ideas.

Methodically, the analysis of authentic footage from a project grounded in design-based-research aiming at developing materials for an electronic portal to be used in teacher's education, has been challenging, especially in regard to the videofootage. Whereas the photographs used for the document analysis were taken systematically after the activities, for the recording of the videofootage it was not always possible to follow the planned protocol, thus leading to data that cannot be standardized. However, the section examined in this article can be considered as a rich pool for qualitative analysis, as has been shown in the previous paragraphs. From a broader point of view, the analysis shows that the short sequence is densely packed with key aspects regarding dialogic learning in crafts and design education that have been highlighted in recent studies. Since parts of the videofootage and the documents discussed can be found on the portal KfUE described in the introductory paragraphs, it is possible for students in teacher education to try and conduct exemplary, simplified microanalysis with similar materials that provide ample opportunities to gain insight into subject-specific teaching and learning processes.

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Necessity of using Problem Based Learning (PBL) and Structural Physical Models on an Educating Structural Course: Case Study of a Structural Systems Course, Master Degree Architecture Students

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Abstract
Teaching structure to architecture students is an important part of the architecture curriculum in faculties. Weak points of architecture students in using their knowledge and data in real environments has caused many problems in professional activities or withheld their essential skills. In this situation they cannot use their abilities and success in their job positions. In this study, we aimed to promote learning structural behavior in a structural systems course, by using a method that is a blend of a Problem Based Learning (PBL) model and a physical model. This was undertaken in structural studies for master degree students in the University of Tehran. In the recent experiment, the theoretical class changed to a workshop and practical class and they learned and studied by working in a group and through hands-on activities to increase their skills and demonstrate abilities, so they are prepared for parallel situations in future. The research method which has been used in this paper is based on the description of the subject feature. According to the research, a PBL model and Structural Physical Model are appropriate ways of understanding the structural behavior without using complicated mathematical formulas. It also provides the best technique for students' preparation and learning.

Keywords
Structural Physical Model, PBL, Structural Design Training, Deployable Pavilion, Educating, Teaching Methods.

Introduction
In the past decade, there is a new orientation to teach theoretical and lecture based courses such as structure with a similar approach and activities. Learning architectural design is usually a cooperative and problem based activity. (Khodadadi, 2015) Several researchers and teachers have tried to present perfect solutions based on different learning theories, teaching methods and experiences in different faculties of architecture.

In research, Dytoc (Figure 1) focuses on alternative teaching methods of illustrating structural behavior and concepts for integration into architectural design thinking. To reach this state, the pedagogic gap between architectural and structural classes needs to be bridged. The teaching methods are based on two viewpoints:

1. To comprehend structures in a graphical manner
2. To understand structures as a potent sculptor of form. (Dytoc, 2009, p.51)

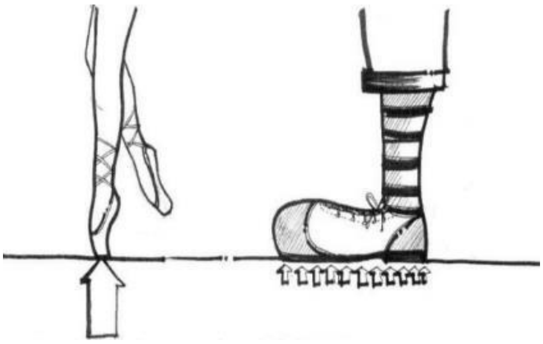


Figure 1: The ballerina, with her pointe shoes, balances on her toes, while Bozo, with his huge size 20-EEE wingtips, flip-flops his way to infamy. (Dytoc, 2009)

Raut and Kalamkar teach structures to architectural students in an innovative and interesting way through model making. The students' outputs are presented and this technique of model making hence is proved to be an effective method for practical understanding of structures concepts. (2019, p.4571) They design and create:

- A Model of Cable-Bridge to understand cable as structural member to take, divert and transfer load.
- A Model of Arch-Bridge to understand arch as member to take and divert load in structure.
- A Model of Truss to understand vertical, horizontal and inclined forces.
- A Tall building to understand wind forces second article.

In the other research, Black and Duff (1994) used advanced structural engineering software, finite elements, to teach structures to architecture students. Students used the computer software to analyze small and large buildings and compare those with their hand calculations. According to Wetzel (2012, p.107), "integrating structures and design encourages students to inform their design decisions with an understanding of material properties, structural systems." Therefore, Wetzel introduced dynamic modeling techniques and large-scale installations to help students visualize structures and integrate structural systems in their design studio.

Callahan, Shadravan, Obasade and Hasenfratz believe that all programs of architecture focus on structures as independent coursework, rather than on integrating pedagogy. To fill this gap, an innovative freshman workshop was developed in a study with a student-centered active learning approach to teach structures. The results show that this method was a fairly successful structures introduction into architectural form, not previously considered. (Callahan, Shadravan, Obasade & Hasenfratz, 2019)

Generally, an architect must be able to conceive and visualize the structure of the building. [1] "An architect should feel what is going on in a structure without needing to count it exactly." (Ilkovič, Ilkovičová, Špaček, 2014, p.59) .One of the methods is to construct Structural Physical Models on a real scale. Severud (1961) points out that an education in structures should be addressed by a direct approach to "build a structure and destroy it and then see what happens: this is by far the best means of recognizing what goes on." (Emami, Buelow, 2016, p.2).

Structural physical models give students the opportunity to observe the process of destruction or alteration of structure, by building and applying forces multiple times, so that they can get a proper insight into the behavior of the structures. On the other hand, in teaching process of such a course, the active participation of students is very important and necessary. The student-centered approaches should be replaced by theoretical and teacher-centered approaches that, through their study time, provide information and practical skills to prepare students for future professional activities.

Generally, architecture has been comprehended as permanent structures. Reasons for this can be explored in an architecture's and designer's desire to design and manufacture building with a long life. Sculptural and monument buildings are the result of this viewpoint. So, these buildings could not change, alter or expand in future. It is apparent that the monument syndrome of static, permanent architecture has continued throughout history into our dynamic times of modern society (Korkmaz, 2004). Therefore, it can be concluded that not much attention has been paid to the development of motion-based techniques in architecture and this is an agreement that has been made between architects and society that has introduced the architecture as immobile, and this is static.

Charles Darwin suggested that the problem of survival always depends upon the capability of an object to adapt in a changing environment. This theory holds true for architecture. In recent years, there has been a growing interest in kinetic design. Architectural applications in responsive kinetic designs arise from issues of spatial efficiency and adaptability. An adaptable space flexibly responds to the requirements of any human activity. Adaptability may range from multi-use interior re-organization to complete structure transformability. Kinetic function in structures provides that the objects in the built environment are physically present only when they are necessary, and disappear or transform when not needed. This is to suggest that a new aesthetic, a new concept of form, is inherent in responsive architecture. (Korkmaz, 2004). Therefore, a constantly changing architecture is needed, a new type of architecture – transformable architecture- that is responsive to the essential characteristic of how our societies "change". Transformable, kinetic, deployable, adaptable, is an extended vocabulary to refer to a building with movable parts or a shape change. Transformable architecture has been used thought out history and continues. It adapts to new uses, responds to change rather than stagnating, and is mobile rather than static. Understanding how it has been conceived, designed, made, and used helps us understand its potential in solving current and future problems associated with technological, social, and economic change (De Temmerman, 2007).

1 - Structure of a building is the regular flow (or controlled) of the physical forces that pass through paths in the presence of robust materials to form a stable three-dimensional space. (Golabchi, Taghizade, Golabchi, 2015, p.31)

The main purpose of our research is based on using Structural Physical Model and Problem-Based Learning so that students can design and build a real-world project, in groups, according to architectural knowledge and creativity with perception of structure behavior and no need for complex numerical calculations.

In this regard, we are going to answer this question: whether the Structural Physical Model along with Problem-Based Learning can be used as a method to understand the behavior of the structures. In this article, after a short review of learning models, we will explain the lesson plan presented and probe the process of students' work.

Teaching structure in architecture

There are different questions in teaching structure to architectural students:

- How to teach a student to understand construction?
- How to perceive construction?
- How to solve construction problems in architectonic pieces?

As Ove Arup stated: "Engineering is a creative activity involving imagination, intuition and deliberate choice, it is exactly what should a student – architecture understand." (Jones & Ove Arup, 2006, p.258) In the process of training, the teacher is searching for innovative manners to change students' perception of the environment and enhance it, so that students can provide suitable and responsive space for users. At first glance, we couldn't find architectural beauty in numerical and mathematical calculations, but these calculations can be presented geometrically and practically with the help of the perception and visualization of students.

A famous picture of Scotland's Forth bridge shows a direct physical experience with a static principle of construction (Figure 2) (Ilkovič et al, 2014)

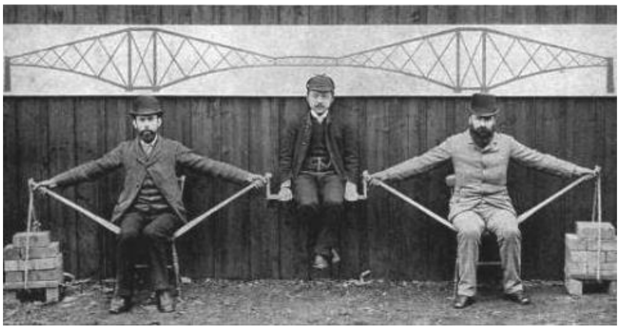


Figure 2: Living Model Illustrating principle of the Forth bridge. (Wikipedia, 2020)

Visualizing is easily acceptable and transformed through visual suggestion and students can receive a physical advance in their concepts of construction. Other examples of practical transfer of force include the idea of scissors-like elements bridge that Chikahiro, Ario & Nakazawa designed and built or scissors- like elements deployable bridge competition in Iran. (figure 3,4)

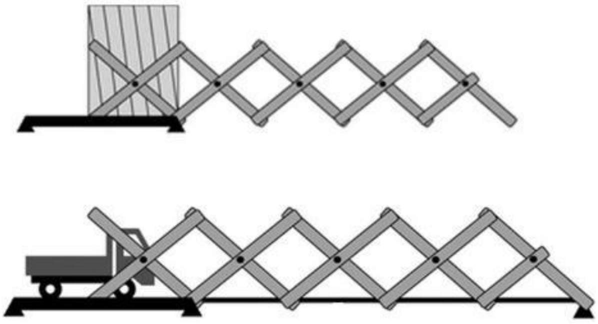


Figure 3: Deployable Bridge Idea (Chikahiro, Ario & Nakazawa, 2016, p. 04016051-2)

Figure 4: Scissors-Like Elements Deployable Bridge Competition- Iran

The Proposed Methods of Structural training for Architectural Students

Problem Based Learning

There are different ways of teaching. One of them is the Problem Based Learning[2] (PBL)[3] (Barrows, 1996). Ilkovic has developed this method and presented it as problem and project based learning (PPBL)[4] ((Ilkovič et al, 2014, Severud, 1961) which is a student-centered and active method, so it contrasts with the teacher-centered method. Problem Based Learning is defined as a high-level process of recognition that requires the use of coordination and control of desirable basic skills. In general, the very important purpose of Problem Based Learning is to make students use their knowledge in real environment in future. It happens in the following ways:

2 - In this method, learning is in the context of research and leads to continuous learning. At first, the teacher sets the problem, then students will collect information. So they present a hypothesis which based on information and finally conclude.

3 -The PBL process was pioneered by Barrows and Tamblyn at the medical school program at McMaster University in Hamilton in the 1960s.

4 - The PPBL method allows students to upgrade their management, planning and self-control capabilities. This method promotes cooperation, responsibility, discipline, patience, tolerance, and other students' basic skills in team working.

- Regular learning of knowledge
- Development of logical and critical skills
- Motivation for continuous learning
- Knowledge and skills Development by team work (communicative skills)

The teacher sets a problem in an assignment, which is solved by relying on previous knowledge, new data, using individual and group abilities and also guidance of the teacher. In teaching studio creation, methods based on problem or project teaching should always be applied and, eventually, as a combination of problem and project teaching. (Zelina, 2000) In both methods, students do their project as team work, which increases the sense of cooperation and teamwork.

Physical Structural Model

Perceiving the behavior of structures during loading can be achieved without the need for any calculations. Answering to questions about structural behavior could lead to perceiving structure. In indeterminate structures, which cannot be fully analyzed, such as Nervi's Aircraft hangar, using perceiving the structure will be an appropriate solution[5]. (Golabchi, 2008) (Figure 6, 7)

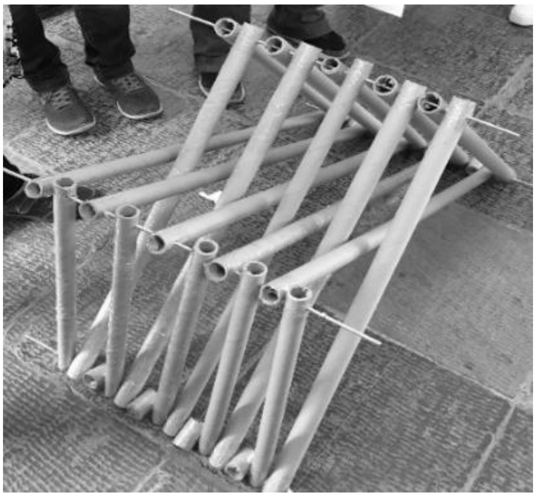


Figure 5: An Example of Structural Physical Model – Deployable and Transformable Chair (Taghizade, Vojdanzade, 2017, p.115)

> *In architecture, modeling is an omnipresent element in the design process; be it in the form of a rough sketch, an inclusive diagram, material artefact, a digital object or a numerical definition. Also in architecture education, the physical model, in particular, has a significant place in the student's toolset, not only as a means of (re)presentation, but as an indispensable medium capable to perform a dual role: resuming and reflective (analysis) or generating and productive (synthesis). (Zurich, 2015, p.4).*

5 - Nervi estimated amount of stress and determined the sizes through simple calculations, sensory and visual reasons and he proved that these dimensions were identical with the structural analysis of the test samples.

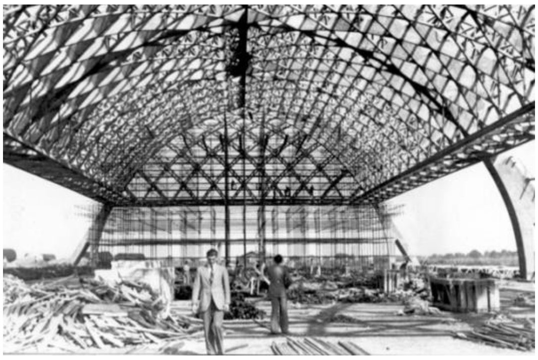


Figure 6: Nervi's Aircraft hangar (BMIAA,2017)

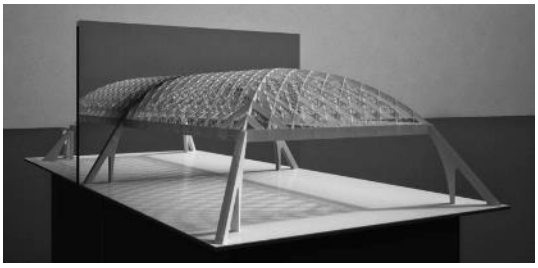


Figure 7: Nervi's Aircraft hangar model, the model as a tool of design and construction (BMIAA, 2017)

Therefore, Structural Physical Model is one of the effective methods for perceiving the structure. In general, modeling is the simulation of an environment of different sizes according the real world and in some cases with different materials.

> *In modeling, at first, the real environmental components are selected based on proportional specific purposes, that is, for each of the components of the real environment, an abstract entity is constructed and communicated in the same way as the actual components to communicate among the abstract entities, the real environment is modeled.* (Figure 5, 8) (Taghizade, Vojdanzade, 2017, p.115)

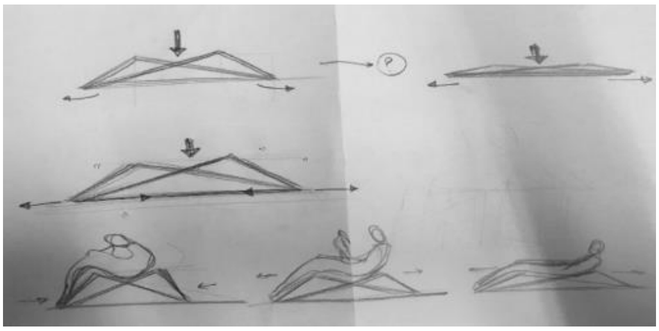


Figure 8: An Example of Structural Physical Model – Deployable and Transformable Chair, (Taghizade, Vojdanzade, 2017, p.115)

"What I hear, I forget; what I see, I remember and what I do I understand". This old Chinese quote may be well-known to us, and can explain the major need for Active Learning[6]. Active learning is a method of learning in which students are actively or experientially involved in the

6 - Active learning is a form of learning in which teaching strives to involve students in the learning process more directly than in other methods.

learning process and where there are different levels of active learning, depending on student involvement. (Bonwell & Eison 1991).

In this method, students must do more than just listen: They must read, write, discuss, or be engaged in solving problems. Also, active learning engages students in two aspects:

- Doing things
- Thinking about the things they are doing. (Renkl, Atkinson, Maier, & Staley, 2002)

Thus active learning has an important role in learning structure for architectural students.

Case Study Research Process –Teaching Structure with Structural Physical Model

According to the materials presented in the previous section, we chose the contemporary structures course at the postgraduate level of the University of Tehran to discuss.

This course talks about new structures and technologies in the contemporary world and is presented theoretically. It is worth mentioning that the postgraduate students studied different courses about structure and construction such as building, concrete and steel structures etc. in the bachelor's degree, so they have sufficient knowledge about structural behavior. But they did not use their theoretical data in real experience. At this educational level, post graduate level, they experience the same method to learn some concepts. But we presented the contemporary structure course, based on the purposed method and a practical section was added.

Deployable structure workshop

Students take part in a workshop during 8 hours and they learn basic concepts and scissors-like elements of geometry by perceiving and understanding the geometry of structures. According to suggested method of Problem Based Learning with Physical Model, we organized the workshop in two parts, theoretical and practical, to achieve our goals:

- Learning basic concept;
- Application of theoretical concepts to practical;
- Development of skills and knowledge by team work;
- The use of skills and gain experience;
- Motivation for continuous learning;
- Preparation to work in professional environments.

Theoretical

The first section, the theoretical part, is short and introduces the history of transformable structures, case studies in nature and man- made building from the past up to now and analyzes the geometry and mechanism of structural motion.

A large group of structures have the ability to transform themselves from a small, closed or stowed configuration to a much larger, open or deployed configuration. These are generally referred to as deployable structures though they might also be known as erectable,

expandable, extendible, developable or unfurlable structures. (Jensen, 2004) But transformable is a comprehensive word to explain these structures.

Transformable structures could be classifed in different types. In this workshop we emphasized scissors-like element structures.

Advantage of scissors-like-structure:

- Retract and expand different times;
- Use all or part of its structure;
- Movement and transportation easily;
- Quick and easy installation;
- Possibility to use in crisis;
- Economical;
- Prefabricated;
- Light and compact;
- Install and disassemble by no specialist or equipment;
- Gathering, transmission and assemble different times.

Scissor units consist of two beams connected by a revolute joint in the middle section of the beam. This joint, scissor or intermediate hinge, allows the beam to rotate around an axis perpendicular to their common plane. A grid structure that consists of linear or surface-like scissor mechanisms can be formed, which can be transformed from a compact bundle of elements to a fully deployed configuration, if we connect a series of scissors – like – elements (SLE) at their end nodes by revolute joints. The mechanism consists of the deployment phase to the service phase, in which it can be beam loads. The upper and lower end nodes of a scissor unit are connected by unit lines. Altering the location of the scissor hinge, intermediate hinge, or the shape of the beams gives rise to three distinct unit types: translational, polar and angulated. (De Temmerman, 2014, Mira, 2010) As previously mentioned deployable scissors-like element structures, pantograph structures, categorize on three part:

- Translational;
- Polar;
- Angulated unit

Translational unit

Two straight identical bars or beams that form a translational unit join by intermediate hinge at the middle of the beams. In a translational unit, the unit lines are parallel and stay parallel during the deployment. By linking these units, a well-known lazy – tong mechanism[7] is formed (Figure 9). Translational unit classifies in two types:

- plane
- curve

7 - lazy-tong is a transformable single-degree-of-freedom mechanism.

The plane unit having identical beams is the simplest translational unit. The curved unit has non-identical length beams so two straight beams differing in length can form curved linkages. A plane or curve linkage is transformed from retracted configuration to deployed position by changing the deployment angle θ. (Figure 9, 10, 11)

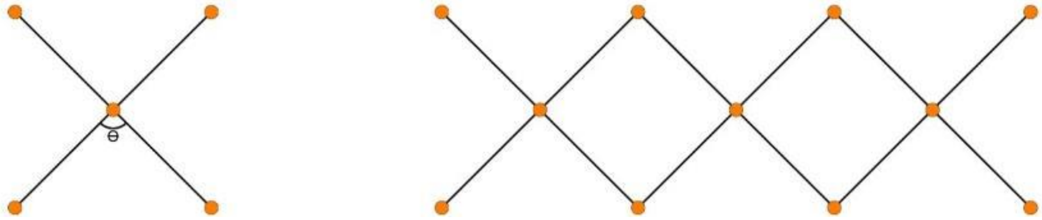


Figure 9: Plane Translational Unit and the Composed Lazy-Tong Scissors Mechanism

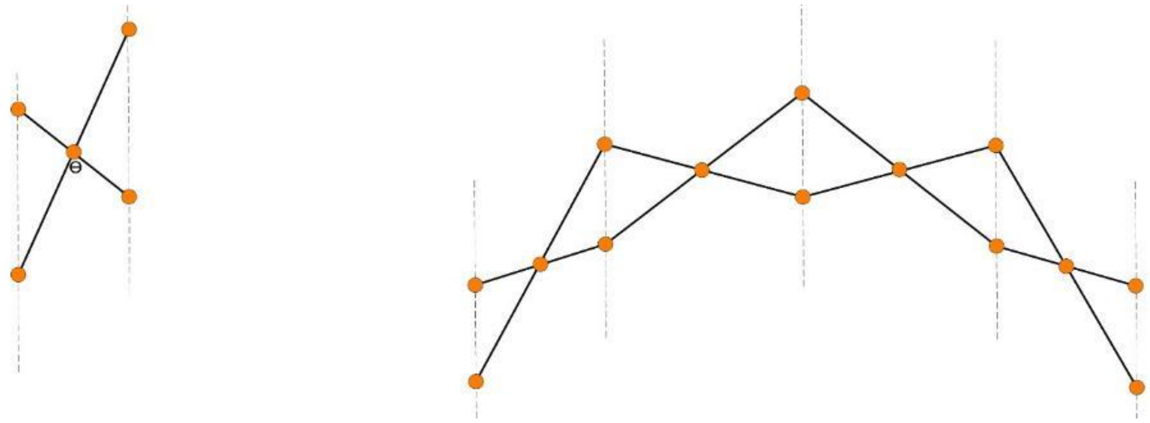


Figure 10: Curved Translational Unit and Linkage

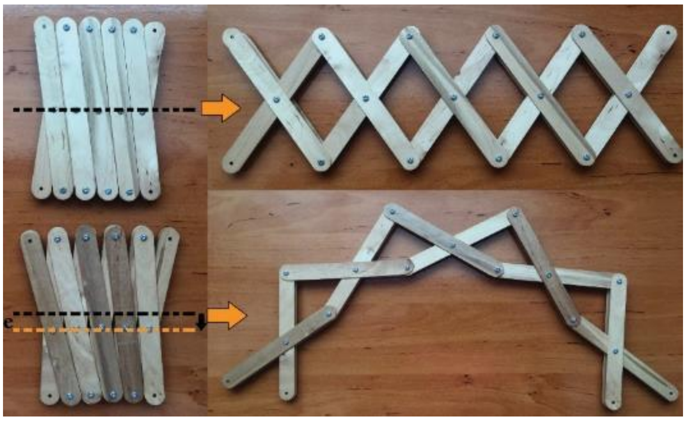


Figure 11: Influence of Hinge Displacement on the Shape.

Polar unit

Polar unit consists of two identical beams with intermediate hinge that moves away from the center of the beams to the end of them. The eccentricity e from midpoint generates curvature during deployment. The unit lines intersect at an angle γ. This angle varies strongly as the unit deploys and the intersection point moves closer to the unit as the curvature increases. (De Temmerman, 2007) (Figure 12)

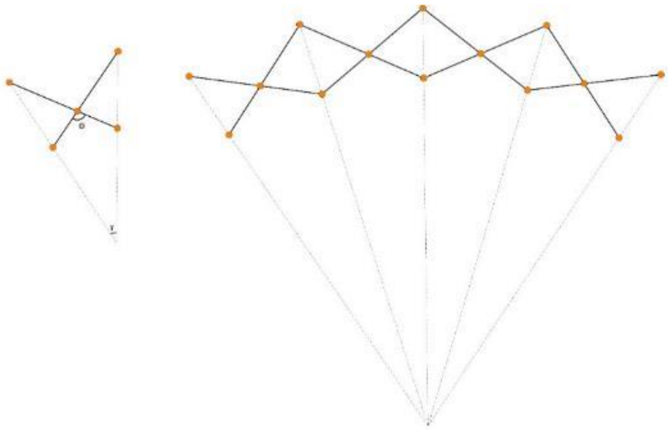


Figure 12: Polar Unit and Linkage in a Close and Open Deployment Position.

Angulated unit

A recent development in the design of scissor-like-structures has been the invention of angulated scissors by Chuck Huberman. A single angulated structure is made out of two symmetric bars hinged and kinked in the center. (Korkmaz, 2004). The major advantage is that, as opposed to polar units, angulated units subtend a constant angle γ during deployment for this to occur, the bar geometry has to be such that α= γ/2. This implies that angulated elements can be used for radially deploying closed loop structures, capable of retracting to their own perimeter, which is impossible to accomplish with translational or polar units, which demonstrate a linear deployment (De Temmerman, 2007). (Figure 13)

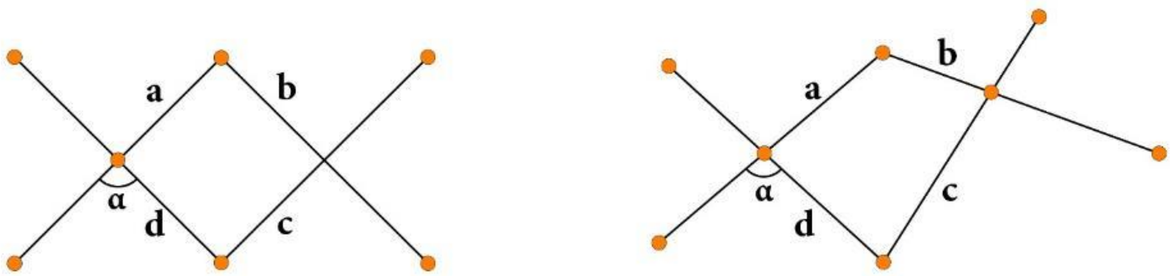


Figure 14: The Deployability Constraint

Deployability constraint

The design of this structure is difficult and complicated but the principle section of design is the deployability constraint. A formula was proposed by Felix Escrig which states that in order to be deployable, the sum of the semi-lengths a and b of a scissor unit has to be equal the sum of the semi-lengths c and d of the adjoining unit. According to the formula, the scissors linkage retracts concertedly into a compact bundle of beams. (Figure 14)

The deployability constraint is written as:

$$\mathbf{a + b = c + d}$$

According to the provided content, they learn the principle concept about scissors-like-structure. Now they know the advantages and disadvantages of them and why they need to use them.

Practical

Based on the subject matters in previous section and the project, students take part in a practical lasting 7 hours. Students make simple and complex physical models in different scales based on scissors-like-structure units with different materials in groups of 4 to 5 people. The selected materials, wooden sticks and straw in different sizes, resemble the main material for the final project in terms of structural behavior. Also students use variable joints for scissors-like-structures units which have been built by students for each material. They experience practically what they learned in the first part of the course.

At the same time the teacher sets a problem that concerns stability development and generalization of modules. Entire groups make an effort to solve problems as quickly and effectively as possible. (Figure 15, 16)

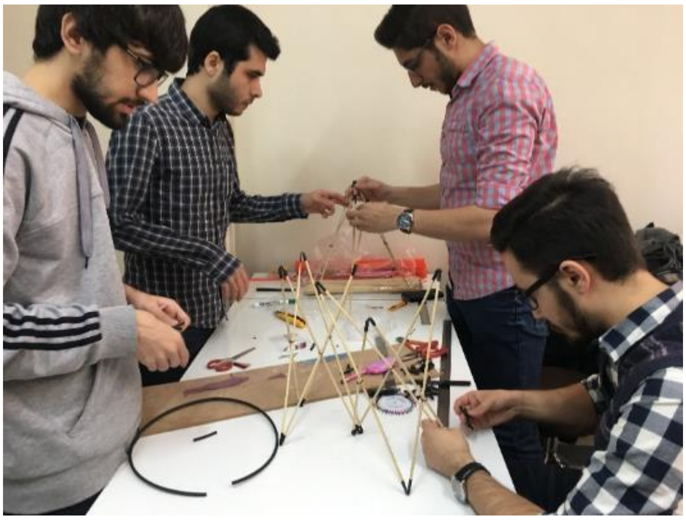


Figure15: Deployable Structure Workshop

Figure 16: Deployable Structure Workshop

At the same time as the modules were made, the students would also combine the models or change them to get new forms. The result of this process is the flourishing innovation and creativity of students. At the end of the workshop, the teacher sets a new project and asked

students to design and construct a pavilion in real scale and an area of 10 square meters with deployable and portable ability with different materials that they learned in practical sections. It should be noted that there are many similarities between the materials that students use in the workshop and the materials that are considered for the final project[8].

Design and construction of final project

Initial design

After attending the workshop, students begin designing and presenting basic ideas and concepts in the form of sketching and etude models in three groups and within one month. They try to design a pavilion with retractable and portable ability based on what they learned in practical part of workshop. After numerous scrutinizes by teachers and according to various abilities of the proposed designs, design No.1 is selected. (Figure 17, 18, 19)

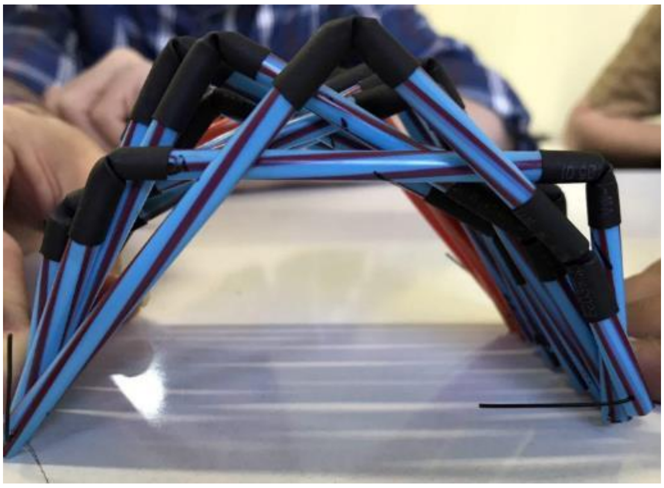


Figure 17: Design No.1

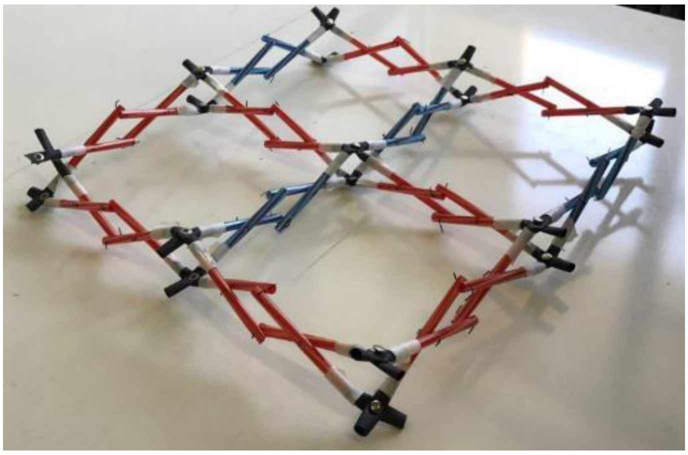


Figure 18: Design No.2

8 - In workshop, students made physical models with wooden sticks and straw, and in the final project, they should use low-density cardboard tubes.

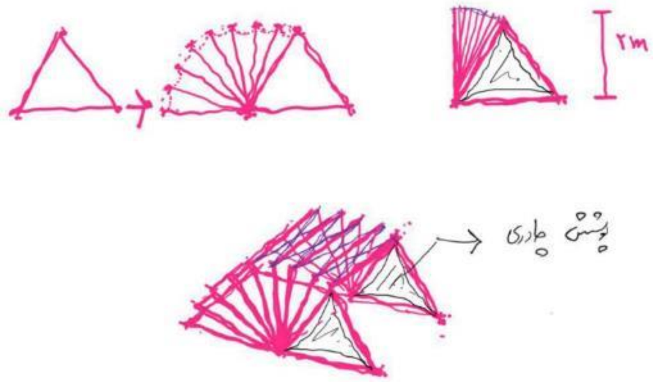


Figure 19: Design No.3

After selecting the project, students have to continue their work in a larger group (19 people). Accurate and regular planning and coordination between the entire group is very important to present a successful project. (One of the most important goals in the selected method) They must continue to design and fix the defects. After that, they are going to build it in real scale.

Final design and construction of the project

Students work on design No.1 and they face different challenges. For example, they had to design different joints to open and close their Pavilion. So students learned how to build three connections and joints that were needed for the final project. (Table 1, Figures 20, 21 & 22)

Table 1: Connection Types

Connection Type	Description
Primary or End Connection	The two elements are connected to each other so that they can be stayed at different angles from zero to 360 degrees.
Intermediate Connection Type 1	The two elements are connected in a place other than the beginning and the end.
Intermediate Connection Type 2	Connecting more than two elements to each other

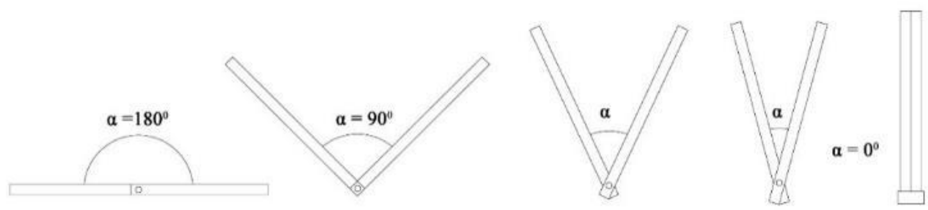


Figure 20: Primary or End Connection

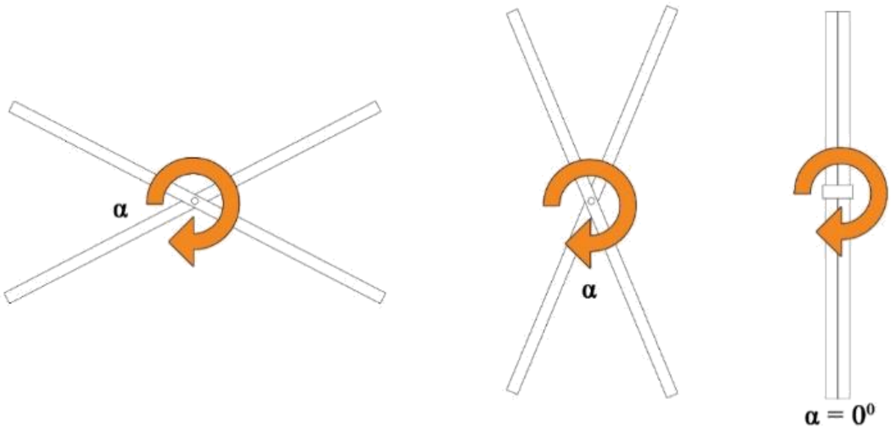


Figure 21: Intermediate Connection Type 1

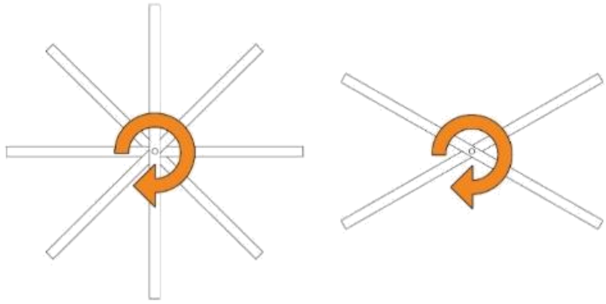
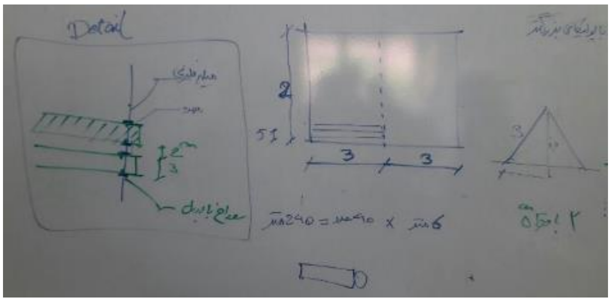


Figure 22: Intermediate Connection Type 2

The primitive design was built in small scale and when they wanted to build it in real scale based on specified requirements, they were confronted with different challenges such as structural instability and buckling and bending of structural elements because of long and slender elements[9]. In designing and building joints the students were not allowed to use any pre-fabricated or cast elements.

In the initial design, the pavilion transformed with difficulty and it needed high occupancy level for opening and closing. (It opened and closed in one axis). Figures 23, 24, 25 Illustrate design, modify and optimize process completely.

9 - Materials include cardboard tubes with a maximum diameter of 4 cm, screws up to a diameter of 4 mm, a U.P.V.C pipe for joints, cable for controlling the opening and structural stability.



Figures 23, 24, 25: Design and Construction Process

- First step: using two different frequent alternating patterns for visual legibility. This design could not retract and deploy in two axes and there are no braces. (Figure 26)

Figure 26: First Step: Using Two Different Frequent Alternating Patterns for Visual Legibility

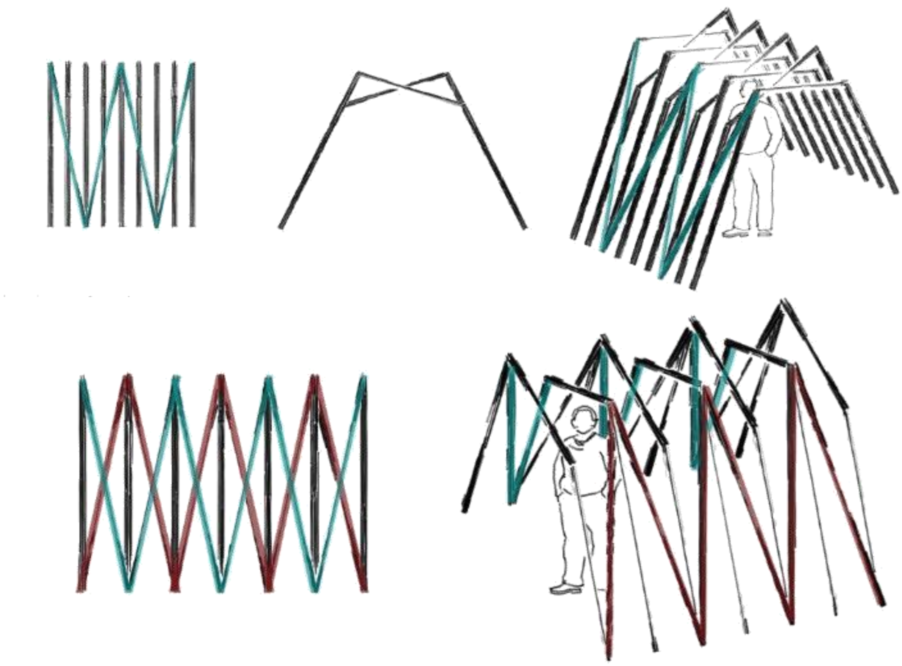


Figure 27, 28: Second Step: Using V-Bracing in Both Side of Pavilion for Lateral Stability and Retract and Deploy in Horizontal Axis.

- Second step: using v-bracing in both sides of pavilion for lateral stability and retract and deploy in horizontal axis. (Figure 27, 28)
- Third step: eliminate additional components and complicated connections to have a simple design and pavilion. (Figure 29, 30)

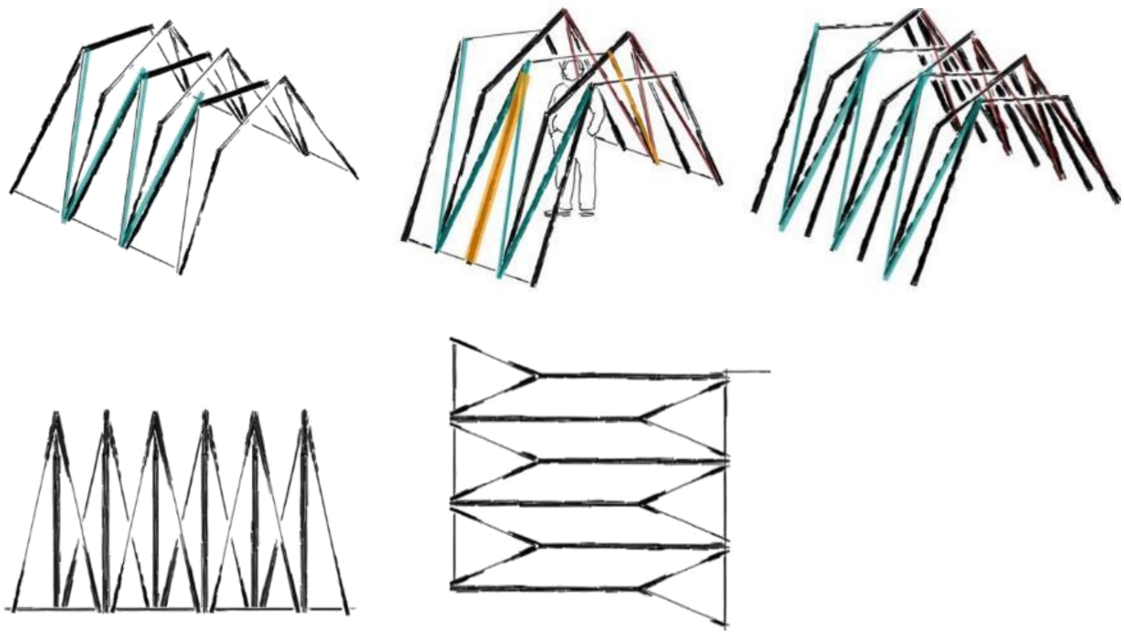


Figure 29, 30: Third Step: Eliminate Additional Components and Complicated Connection to Have a Simple Design and Pavilion.

Finally, they find a solution based on their knowledge about static and structural courses through numerous discussion with each other. The proper approach is to use braces. They were able to adjust the length and number of members by using the braces, as well as the possibility of opening and closing in two directions. In this case the pavilion covers more area.

After designing the projects students build a full-scale modular of the structure (scissors like element structure) with low-density cardboard tubes, bolts and U.P.V.C pipe for joints.
Using low- density tubes caused many problems during construction. (They have to use low-density tubes) Low- density tube with low cross section is like a long column. They had to prevent long column from buckling. Using cable and lateral bracing is a good solution to stable the pavilion and prevent it from lateral force.

This pavilion could develop in 2 orientations easily and could be used as different functions such as pavilion, exhibition, gazebo and temporary shelter. The full- scale structure – pavilion- is the final outcome of our purposed method. It shows students attempts, team working and perception of structural behavior.

Conclusion

There are variety approaches in teaching structure to architectural students. The overarching method that we used for the structural course in University of Tehran is Problem Based Learning with Physical model. Using Problem Based Learning, students could present very good team work during designing to construction. They encountered several challenges, but they were able to provide the appropriate solution and achieve specific goals of Problem Based Learning by scheduling.

The most important goal of this method is that students use their knowledge in the future in professional environment.

This is done through the following:

- Regular knowledge learning
- Development of critical reasoning skills
- Obtaining self- command skills for knowledge search
- Creating motivation for continuous learning
- Developing knowledge and skills for team work (communicative skills)

Using physical model in teaching structure for architectural faculty has many advantages. These models let them explain the structural behavior of a mechanism. They experience different tensions that learned before.

In addition, using Structural Physical Models on various scales contributes greatly in design and construction processes. In this method, students achieve understanding of structure systems, load path and loading by using different structural models without the need for complex numerical calculations, and they realize what is going on in a structure and how forces transfer and what happens in structure?

It is obvious that physical model has a main role in this learning process which implies that students will learn about structural behavior during the process of making physical models. In

this situation the materials used to make the models are key factors of the method. (As we tried to use similar material in workshop and full-scale structure.) Making physical models is an intelligent and effective way to visualize and study the fundamentals of the structural behavior. At the end of term students build a full- scale structure. The full-scale structure gives students a good chance to examine their studies and research. They face different challenges that are different from what they did before in the workshop.

The use of these two methods together promote students' abilities and skills. Also, the final product shows that Problem Based Learning along with Structural Physical Model have a significant impact on learning about structures and it prepares students for the professional world. In other words, learning is the natural result of doing.

The main aim of this project was to find a new and innovative solution to encourage architectural students to learn structural courses easily and perceive structural behavior without using complicated mathematic calculations. Also in this method they were involved in an active learning environment. They gained different experience during design and construction processes, such as the development of team – working and communications skills. Also they constructed their own structure for the first time.

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The Role of Spatial Ability on Architecture Education

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Abstract
Spatial ability is one of the most important key points for technical professions such as architects and engineers and is directly related with the success in educational and professional business life. In this regard, "Techniques of Architectural Presentation", a first semester architectural department course at Gebze Technical University, aims to provide these skills through a variety of techniques such as two-dimensional, three-dimensional representations and models. In this study, the contribution of this course on spatial skills were researched considering students' spatial experiences and innate abilities before architectural education. Pre-test and post-test research were applied and analysed with Statistical Packages for Social Science (SPSS) version 18 software. The pre-test and post-test results have concluded that significant progression was seen between spatial visualisation-spatial perception and spatial orientation tests, while no significant progression was seen between mental rotation and spatial relation- mental rotation tests. The evaluation of the data indicates that the mentioned course is highly effective in the development of spatial skills in total and in the context of spatial visualisation and spatial orientation and the skills can be enhanced by training. Therefore, the syllabus of the course needs to be improved in terms of mental rotation and spatial relation.

Keywords
Spatial Ability, Spatial Experiences, Architecture Education, Architectural Presentation, Mental Rotation.

Introduction
As Cross (2006) clearly stated, design is 'the conception and realisation of new things'. Every discipline that incorporates the process of designing new things (architects, engineers, graphic designers, industrial designers etc.) requires a variety of cognitive skills. Spatial ability is one of the most important of these cognitive abilities. Spatial ability, to visualize an object or a space, mental manipulation of the scene, to animate, rotate, and resize an object in space, is considered necessary and important in all STEM (Science, Technology, Engineering and Mathematics) disciplines (Halpern & Collaer 2005; Nagy-Kondor 2014; Stieff & Uttali 2015). Considered in its most basic form, basic spatial abilities are needed in the simplest actions in daily life, such as driving or finding direction. Further spatial abilities are needed in architecture discipline when designing a building or interpreting the technical drawing of the designed building. Sutton and Williams (2011) state that architecture is foremost in its application of spatial abilities, a component of design cognition, to the creation of space, and comments that

spatial ability plays an important role in architectural education and for the learning experiences of architecture students.
From this point of view, in this study, it is aimed to investigate the effects of the students' spatial experiences and innate abilities on developing individual spatial abilities before architectural education, and to examine the contribution of the “Techniques of Architectural Presentation” (ARCH 101) course in the development of spatial abilities of the Gebze Technical University, Department of Architecture first year students.

Spatial Ability

The idea of spatial ability was expressed by Galton in 1879. The investigations of spatial ability continued in the 1880s with his studies on mental imagery. He defined the visualising faculty as spatial ability and, asserted that the visualising faculty is a natural gift and has a tendency to be inherited (Galton, 1880a,1880b). Since that time, researchers have defined spatial ability in various ways, discussed the components of spatial ability, and developed various methods to measure it (Mohler, 2006). Spatial ability has been a significant area of research in educational psychology since the 1920s -30s (Sorby, 1999), as the concept of spatial intelligence was defined within other factors of intelligence. The spatial ability is a complex area in terms of scope and does not have a clear definition or categorisation. McGee (1979) defines spatial ability as the ability to mentally manipulate, rotate, twist or invert pictorially presented stimuli. Linn and Petersen (1985) approach this from a more conceptual perspective and define spatial ability as skill in representing, transforming, generating, and recalling symbolic, non-linguistic information. Sutton and Williams (2011) form an idea of the concept from an architectural perspective and define spatial ability as the mental manipulative skills required to perform mental processes such as the rotation of objects, the understanding of how objects appear in different positions, and the conceptualisation of how objects relate to each other in space. Schneider and McGrew (2012) define spatial ability as the sensory- and motor- linked abilities and indicate that these abilities are hard to define.

Ilıc and Djukic (2017) state that, in educational psychological research, a distinction is often made between "spatial ability" and "spatial skills”: spatial ability identifies an innate ability, whereas spatial skills define the skill acquired by one’s own effort through training. Sorby (1999) interprets that it is impossible to distinguish between spatial abilities and spatial skills for students at the university level as we have no idea of the training; therefore, the researcher prefers to use the terms "spatial ability" and "spatial skills" interchangeably. In this context, Bishop (1978) narrates that, according to Piagetian theory, spatial skills are developed in three stages (as cited in Sorby 1999; Mohler 2008):

1. Topological Space Stage (Level 1): Two-dimensional (2D) skills, that are acquired by the age of 3-5. (making puzzle or playing with construction toys)
2. Projective Space Stage (Level 2): The ability to visualise objects three-dimensionally (3D). Children often develop this skill in adolescence, with the use of everyday objects.
3. The Transition from Projective Space to Euclidean Space Stage (Level 3): The individuals learn to go back and forth between 2D and 3D. The ability to combine measurement concepts with their projective skills, to visualise the concepts of area, volume, distance, translation, rotation, and reflection are acquired.

The researchers do not mention about one type of intelligence but stress the existent of many intelligences to be learned. In this regard, spatial skills, as a learned skill, have many sub-factors as referred to below.

Factors and Tests of Spatial Ability

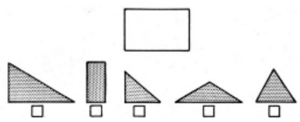
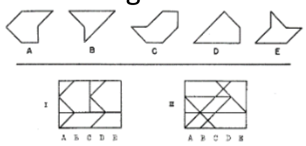
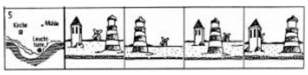
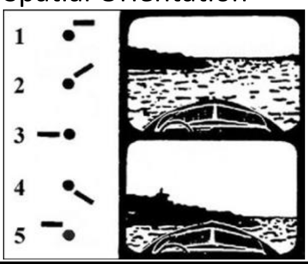
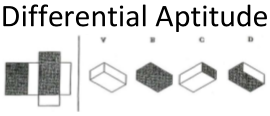
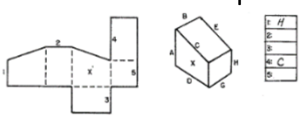
Even though researchers have different approaches in the definition of spatial skills, there is no real consensus about the categorisations of the field. Between 1950 and 1994, during the factorial phase of spatial ability, researchers examined spatial ability more closely and identified the constituent factors of this intelligence (Maresch 2014). Linn and Petersen (1985) had analysed the studies of Carpenter and Just (1986), Cooper and Regan (1982), Guilford (1967), Shepard and Cooper (1982), Thurstone and Thurstone (1941), Cattell (1971) and Vernon (1965) and classified spatial ability under three factors: Spatial Perception, Mental Rotation and Spatial Visualisation. Linn and Petersen (1985) define these factors as: Spatial Perception (SP), Mental Rotation (MR) and Spatial Visualisation (SV). Maier (1994) states that the subject is too complex to be handled under three elements and distinguishes the spatial intelligence under five factors based on several theories of intelligence, meta-analyses and a number of spatial ability studies (as cited in Maier 1996). The five factors of spatial intelligence are:

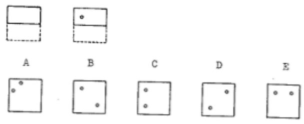
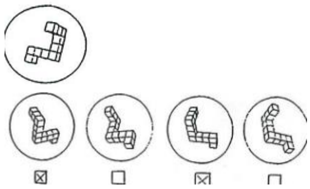
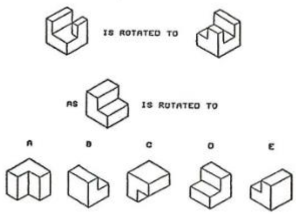
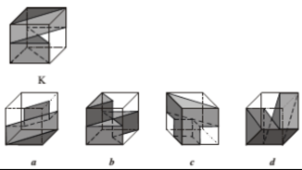
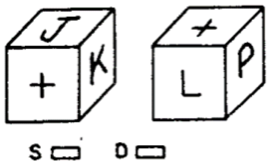
- SP: The ability to identify the horizontal or the vertical location, in spite of distracting information
- SV: The ability to visualise a configuration in which there is movement or displacement among (internal) parts of the configuration.
- SR: the ability to comprehend the spatial configuration of objects or parts of an object and their relation to each other.
- SO: The ability to orient oneself physically or mentally in space.
- MR: The ability to rotate a 2D or 3D figure rapidly and accurately.

Schneider and McGrew (2012) classified spatial ability under eleven factors: Visualisation (VZ), speeded rotation (spatial relations- SR), Closure speed (CS), Flexibility of closure (CF), visual memory (MV), Spatial scanning (SS), Serial perceptual integration (PI), Length estimation (LE), Perceptual illusions (IL), Perceptual alternations (PN) and Imagery (IM) in the Cattell-Horn-Carroll (CHC) theory. Buckley, Seery & Canty (2018) offers 25 factors which are not explicitly represented within the CHC theory and classified spatial ability in two categories as static spatial factors and dynamic spatial factors.

Standardised tools such as spatial ability tests (Mental Cutting Test, Purdue SV Test, etc.) exist to assess spatial ability. In order to present a typology of spatial ability tests, Ilıc and Djukic (2017) grouped 18 spatial ability tests under two categories according to the dimensionality of space (2D or 3D), and subsequently classified the 3D tests into four types based on their complexity, factors that measure, and the execution in architectural studies.

Table 1. Typology of Spatial Ability Tests (Ilic and Djukic 2017).

Group	Type	Number	Task		Factors measured				
					SV	SP	SR	SO	MR
2D		1	Form Board 	Which of the given shapes could be rotated to fit into a given rectangle?	✓		✓		
		2	Card Rotations 	Which shape on the right match to the shape on the left that has been rotated?					✓
		3	Hidden Figures 	Which of the shapes given in the Picture above are contained in complex figures given in the bottom of the drawing?	✓	✓			
3D	Orientation	1	Arial Orientation 	Determine the position of the observer on the left for each view shown on the right.				✓	
		2	Spatial Orientation 	Which of the five offered top views Show the change in orientation of the bow drawn in the pictures?				✓	
3D	Mental Manipulation	1	Differential Aptitude Test 	Which of the solids given right match the unfolded net on the left?					✓
		2	3D Surface Development 	Data is a 3D image of the object and its developed network. Match the letters and					✓

				the numbers to correspond to a given shape and it's developed surface.					
		3	Paper Folding 	Sheet of paper is folded and then drilled as shown in the left picture. Which of the given solutions to the right match to the developed form of paper on the left?					✓
		4	Mental Rotation Test 	Respondents should determine which of the offered rotated solutions below match the given object above.					✓
		5	Purdue Spatial Visualisation Test  	Which of the offered rotated solutions below match the given object in the middle, if the rule of rotation is given in the example on top.					✓
		6	Complement Cube Test 	Which of the solutions given on the right fit to the object on the left to make a cube?			✓		✓
		7	Cube Comparisons Test  	Which of the given pairs of views present the same cube? All the sides of the cube are different.			✓		✓

Significant Factors in the Development of Spatial Skills

Spatial ability, like other types of intelligence, can be an innate ability, or a skill acquired by one's own effort through training or experiences. McKim (1980) states that sketching 3D objects is a significant factor in the development of spatial abilities. Besides, Sorby (1999) remarks the importance of activities that require eye-to-hand coordination to develop these skills and lists these activities as: 1) playing with construction toys as a young child, 2) participating in classes such as shop, drafting or mechanics as a middle school or secondary student, 3) playing 3D computer games, 4) participating in some types of sports, 5) having well developed mathematical skills.

Medina, B. P. Gerson and Sorby (1998) formed a questionnaire in their study to grasp information from the backgrounds of the participants. Questions asked to the participants were related to the types of activities thought to develop spatial skills including: age, handedness, play with construction toys (like Legos® or Lincoln Logs®), previous geometry instruction, work experience, participation in certain sports, their parent's technical instruction, play with video/computer games, previous descriptive geometry instruction, previous art courses, previous technical courses, previous experience with graphics/drafting and project based work experience. The results of the study showed statistical significance in the development of 3-D spatial skills for almost all factors based on the context of the test type.

Baenninger and Newcombe (1989) state that training studies to improve spatial ability can take a number of forms. The simplest type of training is task specific, in which a specific spatial test can be performed to the experimental group. A second type of training is to offer instructions in spatial ability to the experimental group. The third type of training is "spatial experience", in which participants involve experience not directly linked to particular spatial ability. Baenninger and Newcombe (1989) remark that when a PreT and PosT research is used, it can be seen that a spatially rich environment, such as a technical drawing course, increases spatial ability more than task-specific training. Pütz (2000, 2001) states that descriptive geometry courses, the training of 3D imagination, are significant for understanding the various ways of projection for architectural drawings spatial objects in the architect's field of activity.

Uttal, Miller and Newcombe (2013) examined 206 studies using a meta-analysis technique to answer spatial ability can be improved by spatial training. Like playing video games, practicing spatial tests, graphic/design courses improved spatial skills and well designed and intensive training can have lasting benefits. Another finding about their analysis is that children and adults as well as women and men responded equally to training. But more research is necessary to determine difference with each mentioned group. Stieff and Uttal (2015) highlighted that extended training in excess of several months to yield lasting benefits for spatial training interventions may be required, and the impact of such training may not be seen until much later in a student's educational life or developmental trajectory.

Besides the factors that establish direct proportion with the development of spatial skills, there are also factors that have inverse proportion with spatial skills, such as age. Studies in Developmental Research have found that age affects spatial ability; spatial ability improves with age in childhood but declines with age in adulthood (Mohler, 2008). Another factor that does not establish a direct proportion to spatial skills, such as the age factor, is the sex factor. However, there is still a debate about how gender affects spatial skills.

A significant part of spatial skills literature focuses on sex differences. According to researchers in psychology and the social sciences, males and females differ in spatial ability. Masters and Sanders (1993) state that sex differences have remained at approximately 0.9 standard deviation units for almost two decades. Voyer, Voyer and Bryden's (1995) meta-analysis supports the idea that sex differences are not generally declining and depends on the test used. Halpern and Collaer (2005) state that there has been much interest in the possibility that sex differences in cognitive abilities, in general, and in spatial abilities, are decreasing.

The Role of Spatial Ability in Architecture

The spatial ability which is effective on architecture profession also has been emphasised by the researchers. In the study of Ilıc and Djukic (2017), it was stated that spatial skills are very important for technical professions and are required when enrolling in technical studies, especially in the studies of architecture. Williams and Sutton (2011) also indicated that spatial ability should therefore be considered a fundamental skill in design-based disciplines, but its importance is not always understood or given the attention it deserves. Karlins, Schuerhoff and Kaplan (1969) investigated architectural creativity for 17 undergraduate architectural students. It was concluded that architectural creativity may be related to "visualisation" as a spatial ability. Sutton and Williams (2011) conducted a research project focusing on the relation of spatial ability and course performance of first year architecture design studio students. As a result of the research, it was determined that spatial skills developed more in the freehand study period (first half of the school year), than in the CAD study period (second half of the school year). The researchers did not observe any difference between the spatial ability of females and did not find a significant relationship between the ability of university entrance exam scores and spatial skills.

In order to identify the relationships among spatial ability, creativity and studio performance, Cho (2012a) conducted an exploratory study with 21 freshman architecture students. The results of the study indicate that studio performances cannot be used to explain students' creativity or spatial ability levels.

At Gebze Technical University, technical drawing education is given as a separate course entitled ARCH 101 Techniques of Architectural Presentation. The aim of the course is to provide students with a variety of techniques such as 2D representations (plans, sections and elevations of a project) and 3D representations (physical or computer-generated models and perspectives) to formulate each stage of the architectural design process. The ability to read, interpret, and visualise 2D to 3D in the scope of this course is known as spatial ability (Cho 2012b).

This course is given for six hours a week in the fall term of the first year in the Department of Architecture in Gebze Technical University. It is a two-hour theoretical and four-hour applied course. The course for undergraduate students who are new to architecture education plays an important role in transferring the design ideas they think about mentally to drawings and developing architectural expression techniques.

In this course, each subject was taught theoretically face to face in two drawing ateliers or the computer laboratory for two hours per week. After the theoretical lecture, relevant practices for problem-solving about that subject were provided under the guidance of instructors and

supported by hand/computer drawings and models. Extracurricular individual studies were requested to be completed as assignments at the end of each lesson. The assignments were checked by the instructors and the assignments in which the mistakes were marked given back to the students. The assignments that could not be completed by most students were repeated with different practices. The syllabus and assignments of the course for 2018-2019 fall term and spatial abilities expected to be acquired by students are given below (Table 2).

Table 2. The syllabus and assignments of the course and related spatial abilities.

Weeks	Teaching activity/ Syllabus	Assignment No	Definition	Spatial Ability				
				SV	SP	SR	SO	MR
1	outdoor freehand sketching, usage of architectural drawing tools with samples (2D)	No Assignment			✓	✓		
2	technical drawing, drawing types, hatching techniques (2D)	A1	Lines		✓	✓		
		A2	Shapes					
		A3	Alphabet					
3		A4	Hatches		✓	✓		
		A5	Pavement Plan and Section					
		A6	Stair Sections					
		A7	Free Hand Drawings					
4	projection drawings, isometric projection (projection planes), computer aided design geometry - (2D and 3D)	No Assignment		✓	✓	✓	✓	✓
5		A8	Model (Projection Plans)	✓	✓	✓	✓	✓
6	scale and measurement concepts (2D)	A9	Projection Drawings		✓	✓		
7	projection drawings (projection drawings of geometrical object compositions by scaling, plan, section, elevation) scale and measurement concepts with simple plan drawings and computer aided projection drawings (2D and 3D)	A10	Plan of geometrical objects	✓	✓	✓	✓	✓
		A11	Sections of geometrical objects					
		A12	Elevations of geometrical objects					
		A13	Elevations of geometrical objects					
8		No Assignment		✓	✓	✓	✓	✓
9	Mid Term Exam							
10		No Assignment		✓	✓	✓	✓	✓

11	drawing a sample project (masonry building, reinforced concrete building) (2D and 3D)	A14	1/100 plan	✓	✓	✓	✓	✓
		A15	1/100 section					
		A16	1/100 elevation					
12		A17	1/50 plan	✓	✓	✓	✓	✓
		A18	1/50 section					
		A19	1/50 elevation					
13	perspectives drawings, types of perspectives, isometric, diametric, trimetric perspectives, one-point and two-point perspectives (2D and 3D)	A20	One-point perspectives	✓	✓	✓	✓	✓
		A21	Two-point perspectives					
14		No Assignment		✓	✓	✓	✓	✓

Some of the assignments during the course are detailed below (Figure 1, 2).

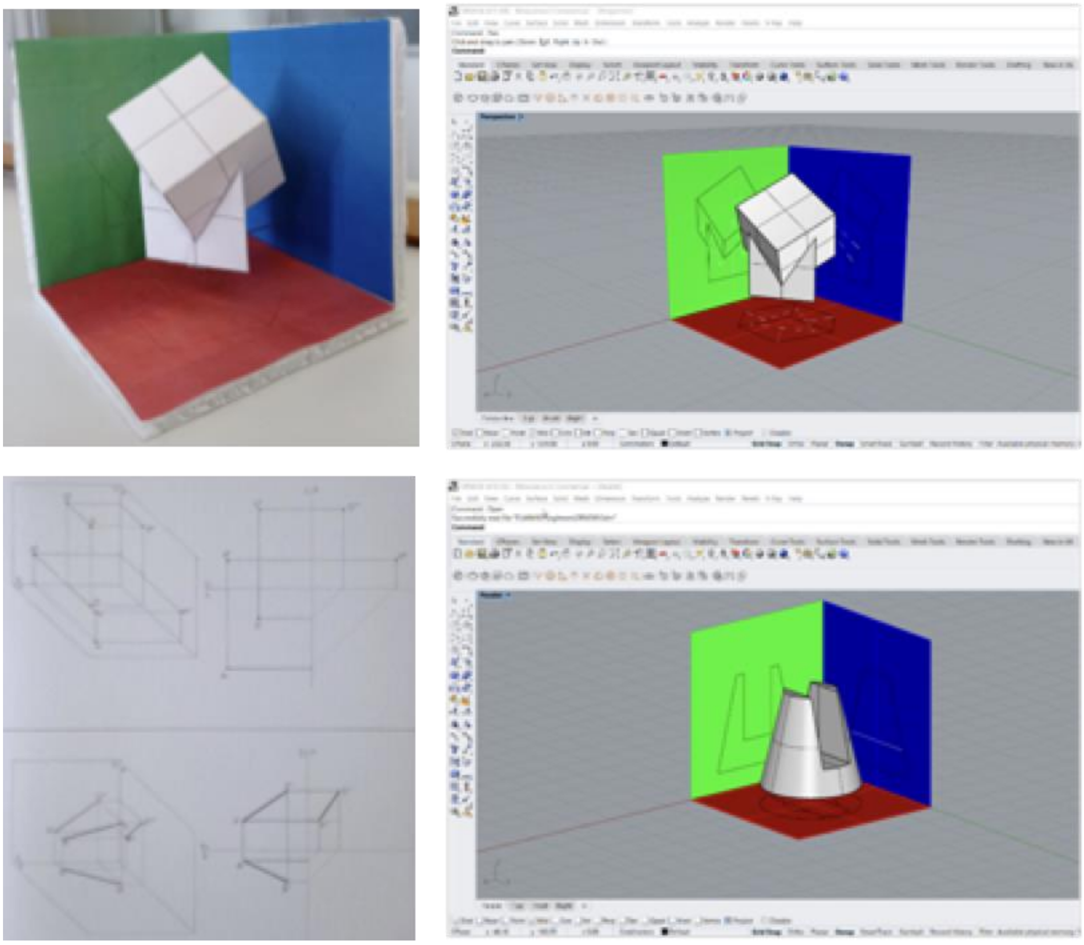


Figure 1. The example of projection drawings and model assignment (A8).

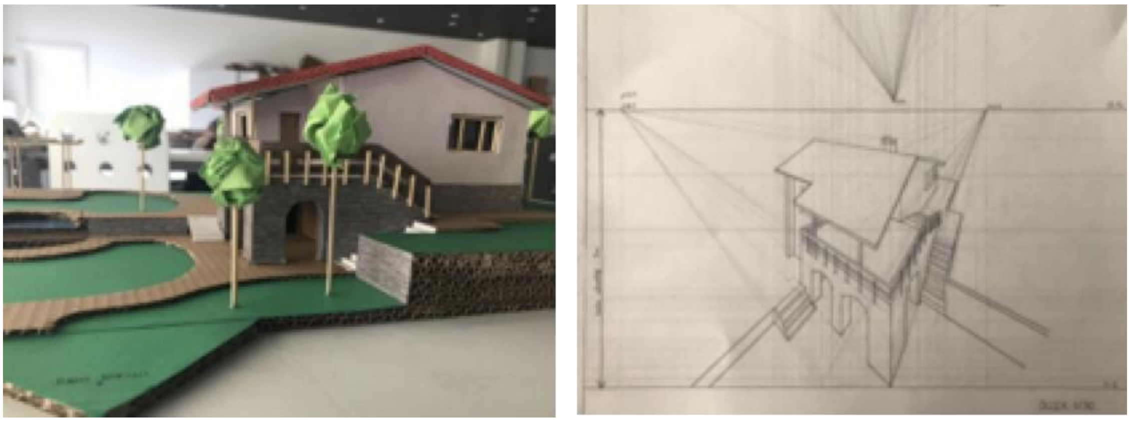


Figure 2. The example of two-point perspective assignment (A21).

Research Aim and Methodology

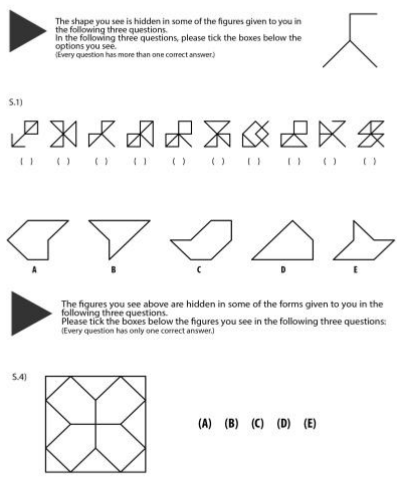
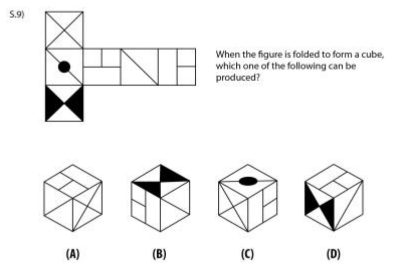
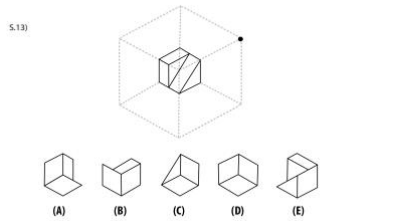
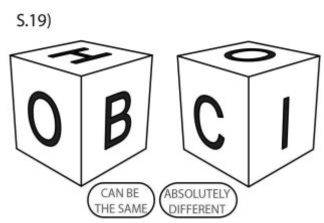
Williams and Sutton (2011) emphasised that spatial ability in the past was considered an innate ability, but recent research has created an awareness that this may not be the case in all situations. In this viewpoint, the aim of this study is:

- to investigate the effects of the students' spatial experiences and innate abilities on developing their spatial skills before architectural education
- to examine the contribution of ARCH 101 course in the development of spatial skills of the architecture students.

For these two research objectives, Pre-test (PreT) and Post-test (PostT) research were applied for the architecture students. The significant limitation of this study was the number of first year architecture students taking the course. The scores of 96 students were evaluated responding to the first and second tests among 124 architecture students. A questionnaire was done before the first test that contains the information about the students considering the factors affecting the spatial skills emphasised in the literature. Age, mother and father profession, gender, university admission score, active used hand, sketching experiences, work experiences, whether computer games have been played, whether geometry and art lessons have been taken before, whether sports have been participated in, whether puzzle and/or construction toys have been played were questioned in this part of the test. In the description part for some questions in the questionnaire, the students were asked to indicate how long experience they had in sketching, working, playing computer games, and taking lessons, etc. Long-term experiences were taken into account in the evaluations.

Design of the test questions: In order to evaluate the student's development between PreT and PostT in terms of spatial ability, the same question types with the same difficulty were prepared for each test. The PreT and PostT were formed by subtests of 24 questions to investigate the students' spatial skills. Detailed contents of the tests can be seen at Table 3.

Table 3. Contents of the PreT and PostT.

<table>
<tr><th>Number of Questions</th><th>Spatial Ability Test</th><th>Spatial Ability Factor</th><th>Question Examples</th></tr>
<tr><td>6</td><td>Hidden Figures and Hidden Patterns Tests
Questions 1-6 (Ekstrom, French, Harman, and Dermen, 1976)</td><td>SV+SP</td><td>
</td></tr>
<tr><td>6</td><td>Differential Aptitude Test
Questions 7-8 (Kösa, 2011)
Questions 9-10 (Carter and Russell, 2007)
Questions 11-12 (URL 1)</td><td>MR</td><td>
</td></tr>
<tr><td>6</td><td>Arial Orientation Test
Questions 13-18 (Kösa, 2011)</td><td>SO</td><td>
</td></tr>
<tr><td>6</td><td>Cube Comparison Test
Questions 19-24 (Ekstrom, French, Harman, and Dermen, 1976)</td><td>SR+MR</td><td>
</td></tr>
</table>

Test was formed based on Maier's spatial ability factors differentiation. Six questions were asked for every spatial ability factor (SV, SR, SP, MR, SO). The pilot study of the test was done, and the test time was determined to be one hour given in total for all subtests of 24 questions to focus the students on the test.

Sorby (1999) states that most spatial skills tests have been developed to assess a person's skill-level in the first two stages of development. From this point of view, the 2D tests, Form Board, Card Rotation or Hidden Figures, that are mentioned in the list of Ilic and Djukic (2017) assess only topological spatial skills and are not of significant interest for architecture education. On the other hand, these 2D tests indicate students' background spatial experience; therefore, hidden figures and hidden patterns tests were included in the test. Ilic and Djukic's (2017) Typology of Spatial Ability Tests table was taken as reference to compose the other three sections of the test.

Implementation of the test: The PreT intended for investigating the effects of the students' experiences and characteristics on developing their spatial skills was applied in the first week before the first lecture. The second test intended for examining the contribution of ARCH 101 course in the development of spatial skills of the students was applied in the fifteenth week after all lectures. The second test was applied as a final exam to increase the student participation.

Evaluation of the test: The results of the test were evaluated for 96 students responding to the first and second tests. Each question in the test was rated as ten points. The SPSS Statistics 18 programme was used to analyse the results. The complete road map of the research can be seen at Figure 3.

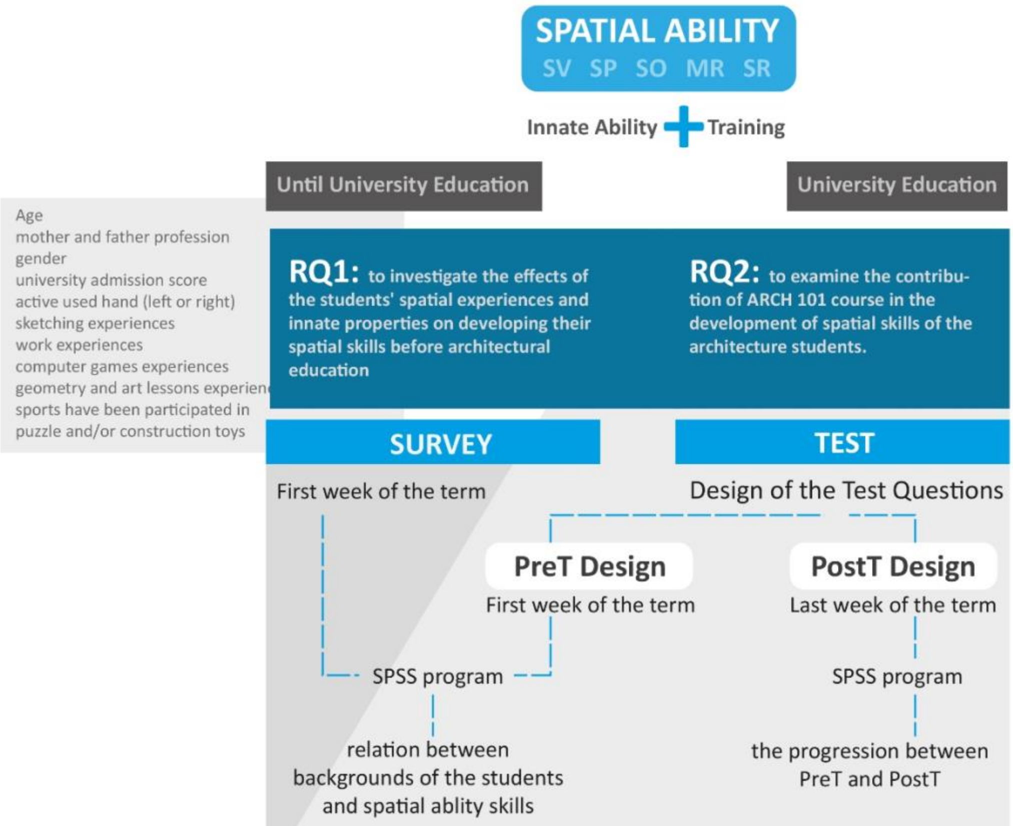


Figure 3. The road map of the research.

Findings of the Research

This study was conducted on all first-year undergraduate students in the Architectural Department at Gebze Technical University. The study group was comprised of 46 (48%) female

students and 50 (52%) male students. It was indicated that 79 % of the participants' mothers are housewives, 4% nurses, 3% civil servants, 3% teachers, 2% cooks, 2% workers, 2% retired, 1% architects, 1% self-employed and 1% have other professions.

Regarding the profession of participants' fathers, 20% are self-employed, 9% retired, 9% workers, 8% civil servants, 5% soldiers, 5% other, 4% police, 3% teacher, 3% driver, 3% accountant, 3% lecturer, 2% contractor, 2% construction technician, 2% religious' officer, 1% automation technician, 1% mechanical engineer, 1% mechanical technician, 1 % computer engineer, 1% naval engineer, 1% cook, 1% banker, 1% barber, 1% farmer, and 1% operator. The students' admission scores are between 405 and 438. The questionnaire formed to elicit information from the backgrounds of the students was analysed with the scores of the PreT. Any statistically significant differences between backgrounds and PreT were not found. The graphical presentation of the study group is given in Figure 4.

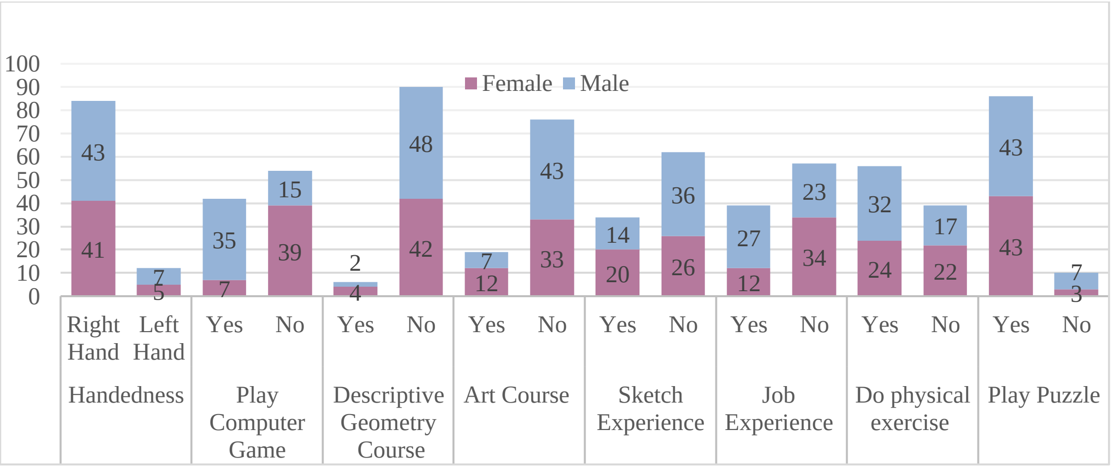


Figure 4. Information from the backgrounds of the study group.

Collected data from PreT and PostT were analysed using the SPSS software. The students' PreT and PostT scores were analysed to determine if there were significant sex differences. Table 4 points out mean, std deviation and std error results of PreTest and PostTest scores according to gender variable. According to the analysis results, the mean values of the PreT and PostT, PreT_SV+SP and PostT_SV+SP, PreT_SO and PostT_SO and PreT_SR+MR and PostT_SR+MR scores increased; mean values of PreT_MR and PostT_MR scores decreased in men and women. There is more difference for men than women in the mean value of PreT and PostT scores (Table 4).

Table 4. Mean, std deviation and std error results of PreTest and PostTest scores according to gender variable.

Variable		Statistics	PreT	PostT	PreT SV+SP	PostT SV+SP	PreT MR	PostT MR	PreT SO	PostT SO	PreT SR+MR	PreT SR+MR
Sex	Female	Mean	154.29	185.19	7.98	9.59	7.17	6.77	5.46	5.94	5.27	8.55
		Std. Deviation	30.12	25.11	1.78	0.80	1.73	2.28	2.942	2.93	1.57	1.29
		Std. Error	4.44	3.70	0.26	0.118	0.26	0.33	0.43	0.43	0.23	0.19
	Male	Mean	152.66	193.97	7.63	9.42	6.64	6.36	6.06	7.70	5.36	8.83
		Std. Deviation	35.36	25.22	2.22	1.01	1.80	2.01	3.32	2.51	1.97	1.31
		Std. Error	5.00	3.56	0.31	0.14	0.25	0.28	0.47	0.35	0.27	0.18

A Repeated-measures ANOVA test was conducted to examine the effect of gender variable on the progression between PreTest and PostTest. Homogeneity of variance (HOV) was examined using the Levene's test. If the variances are homogeneous, "sphericity assumed" row value was interpreted for a relation between gender and test score values, and the Greenhouse-Geisser row value if the variances are not homogeneous. The variances were found to be homogeneous as a result of the Repeated-measures ANOVA test performed between the PreT and PostT scores in the context of gender in Table 5 (sig> 0.05). Therefore, considering sphericity assumed row in Table 6, it was concluded that gender does not affect the PreT and PostT scores (F = 3.434; sig = 0.067> 0.05). That there is a minor difference between the mean PreT and PostT scores of men and women supports this result.

Table 5. Levene's test of equality of error variance for the progression between PreT and PostT in the context of gender.

	F	df1	df2	Sig.
PreT	2,530	1	94	0.115
PostT	,071	1	94	0.791

Table 6. Test of within subjects effects.

Source		**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Test*Gender	Sphericity Assumed	1298.485	1	1298.485	3.434	0.067	0.035
	Greenhouse-Geisser	1298.485	1	1298.485	3.434	0.067	0.035
	Huynh-Feldt	1298.485	1	1298.485	3.434	0.067	0.035
	Lower-bound	1298.485	1	1298.485	3.434	0.067	0.035

Significant results were found in PreT and PostT between sexes in SO but not in MR, SV+SP, SR+MR. The variances were found to be homogeneous as a result of the Repeated-measures ANOVA test considering the progression between the PreT_SO and PostT_SO scores (sig> 0.05) (Table 7). Therefore, considering sphericity assumed row in Table 8, it was concluded that gender affects the PreT_SO and PostT_SO scores (F = 4.309; sig = 0.041< 0.05). Figure 5 shows that males make more progress than females between the PreT_SO and PostT_SO scores.

Table 7. Levene's test of equality of error variance for the progression between PreT+SO and PostT+SO in the context of gender.

	F	**df1**	**df2**	**Sig.**
PreT_SO	2.157	1	94	0.145
PostT_SO	2.157	1	94	0.145

Table 8. Test of within subjects effects.

Source		**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Test_SO*Gender	Sphericity Assumed	15.975	1	15.975	4.309	0.041	0.044
	Greenhouse-Geisser	15.975	1	15.975	4.309	0.041	0.044
	Huynh-Feldt	15.975	1	15.975	4.309	0.041	0.044
	Lower-bound	15.975	1	15.975	4.309	0.041	0.044

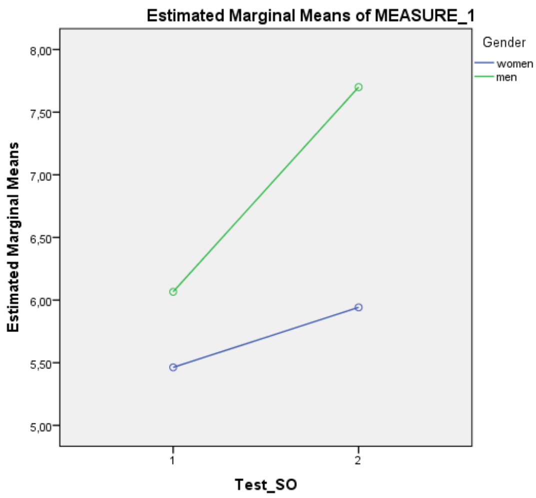


Figure 5. Profile plots of the PreT_SO and PostT_SO scores in the context of gender.

The compliance of the data to the normal distribution was analysed by Kolmogorov-Smirnov test, and the difference values of the PreT and PostT scores were found. It was seen by the normality test that the test result is fit to the normal distribution (Kolmogrov-Smirnov test sig. = 0.096).

Table 9. Paired sample test.

		Correlation	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of The Difference		t	df	Sig.(2-Tailed)
						Lower	Upper			
Pair 1	PreT_SV+SP PostT_SV+SP	0.447	-1.7086	1.8095	0.1846	-2.0753	-1.3420	-9.252	95	0.000
Pair 2	PreT_MR PostT_MR	0.062	.33681	2.71900	0.2775	-.21412	.88773	1.214	95	0.228
Pair 3	PreT_SO PostT_SO	0.577	-1.0804	2.77018	0.2827	-1.6417	-.51916	-3.821	95	0.000
Pair 4	PreT_SR+MR PostT_SR+MR	0.087	-3.375	2.11718	0.2160	-3.8039	-2.9460	-15.61	95	0.000
Pair 5	PreT-PostT	0.567	-36.321	27.8511	2.8425	-41.964	-30.678	-12.77	95	0.000

The sections of the tests were compared separately in order to measure which factors of the spatial ability were supported in the course. There is a significant, positive, and moderate relationship between PreT_SV+SP and PostT_SV+SP (Corr = 0.447). As a result of the test, a

statistically significant difference was found between PreT_SV+SP and PostT_SV+SP scores at the beginning and end of the course (sig = 0.000 <0.05). It was concluded that this difference would be between -2.0753 and -1.3420 at the 95 % confidence. When the mean value is considered, it can be interpreted that the course is effective in the development of the students' spatial skills in terms of SV+SP, as the mean value is found negative after the course (Table 9).

No significant relationship was found between PreT_MR and PostT_MR (Corr = 0.062). As a result of the test, no statistically significant difference was found between PreT_MR and PostT_MR scores at the beginning and end of the course (sig = 0.228> 0.05). When the mean value is considered, the mean value after the course is found to be positive and it can be interpreted that the course is not effective in the development of the students' spatial skills in terms of MR (Table 9).

There is a significant, positive, and moderate relationship between PreT_SO and PostT_S0 (Corr = 0.577). As a result of the test, a statistically significant difference was found between PreT_SO and PostT_S0 scores at the beginning and end of the course (sig = 0.000 <0.05). It is concluded that this difference would be between -1.6417 and -.51916 at the 95% confidence interval. When the mean value is considered, it can be interpreted that the course is effective in the development of the students' spatial skills in terms of SO, as the mean value is found negative after the course (Table 9).

There is a significant, positive, and weak relationship between PreT_SR+MR and PostT_SR+MR (Corr = 0.087). As a result of the test, a statistically significant difference was found between PreT_SR+MR and PostT_SR+MR scores at the beginning and end of the course (sig = 0.000 <0.05). It was concluded that this difference would be between -3.8039 and -2.9460 at the 95% confidence interval. When the mean value is considered, it can be interpreted that the course is effective in the development of the students' spatial skills in terms of SR+MR, as the mean value is found negative after the course (Table 9).

There is a significant, positive, and moderate relationship between PreT and PostT (Corr = 0.567). As a result of the test, a statistically significant difference was found between PreT and PostT scores at the beginning and end of the course (sig = 0.000 <0.05). It was concluded that this difference would be between -41.9644 and -30.678 at the 95% confidence interval. Data about the negative mean value after the course highlight that the course is effective in the development of the students' spatial skills in total (Table 9).

The distribution of spatial ability factors on the syllabus of the course is given in Table 2. The percentages of the factors table have been composed based on the syllabus of the course. As seen in Figure 6, MR, SO and SV factors have low percentages compared to other factors on the syllabus of the course. A statistically significant progression was observed in SV+SP, SO, and SR+MR factors, but no significant difference could be observed in MR factor. Although in Figure 6 the percentage of the MR factor is similar with SO and SV factors, which have statistically significant progression, students could not progress only in the MR test between PreT and PostT scores of this study (Figure 6).

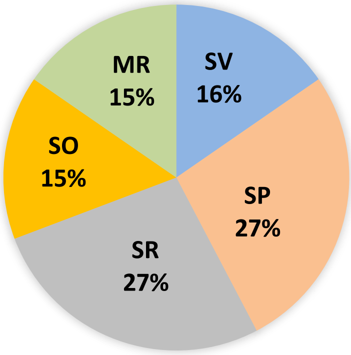


Figure 6. The distribution of spatial ability factors on the syllabus of the course.

Table 10 shows the minimum, maximum, mean, and standard deviation results of the test scores. According to these results, a difference was observed between the mean values of PreT and PostT scores. The PreT values are between 80 and 210, while the PostT values are between 125.72 and 240.00. Standard deviation values generally showed a decreasing trend in PostTests.

Table 10. Descriptive statistics for PreT and PostT scores.

Test Score	n	Min	Max	Mean	Std. Deviation
PreT	96	80.00	210.00	153.449	32.796
PostT	96	125.72	240.00	189.770	25.428
PreT_SV+SP	96	0.81	10.00	7.801	2.0232
PostT_SV+SP	96	6.43	10.00	9.510	0.9211
PreT_MR	96	3.33	10.00	6.899	1.8071
PostT_MR	96	0.00	10.00	6.562	2.1468
PreT_SO	96	0.00	10.00	5.777	3.1481
PostT_SO	96	0.00	10.00	6.857	2.8497
PreT_SR+MR	96	0.00	10.00	5.322	1.7832
PostT_SR+MR	96	3.33	10.00	8.697	1.3068

PreT and PostT scores of the students were compared and the success progression of the students was listed. Among 96 students, 6 students' scores progressed between 80-100%, 6

students progressed between 60-80%, 13 students progressed between 40-60%, 29 students progressed between 20-40%, 34 students progressed between 0-20%, while 8 students could not present an increase of scores. 54 students showed 20-100% progression among PreT and PostT scores.

The research was re-evaluated on the basis of the pre-test in order to observe the progression between the pre-course spatial ability levels and the post-course spatial ability levels. The same five scales were used to examine the students' performances in the PreT. Accordingly, 11 people scored 80% and above, 49 people scored 60-80%, 32 people scored 40-60% and 4 people scored 20-40%. Considering the progression rates of the students' scores in the PostT, it was observed that 80% and above group progressed by 2.78%, 60-80% group progressed by 18.03%, 40-60% group progressed by 43.11% and 20-40% group progressed by 70.18%.

Discussion

The Information from the Backgrounds of the Students

Gender and age*:* Student PreT and PostT scores were analysed to determine if there were significant sex differences, 0.06 significant was found between the tests. Although Halpern and Collaer (2005) apprise that if the Women's Movement that began in the 1960s provided equivalent learning opportunities for girls and boys, and if cognitive sex differences are primarily social in origin, then these sex differences should diminish and eventually disappear with changes toward a more sex-neutral society, male students succeed better than women students in the research. Besides that, significant difference between man and female was also found at SO progression in PreT and PostT. As per Lawton's (1994) study on gender differences in way-finding strategies, women are more likely to report using a route strategy (attending to instructions on how to get from place to place), whereas men are more likely to report using an orientation strategy (SO - maintaining a sense of their own position in relation to environmental reference points). The average ages of 96 students in the study range between 18 years and 24 years, the average age is 20. 2D and 3D skills can be improved for this age range.

Mother and father profession*:* 79% of the mother profession of the students to whom the questionnaire was applied is housewife. 46 % of the father's profession of the students is self-employed, retired, workers and civil servants. Although there was no statistically significant relationship between the mother and father profession factor, the findings of the semi-structured face-to-face interviews with the students who achieved a score of 80% or more in the PreT highlight that the family factor (mother, father, uncle, aunt, etc.) was effective in the development of spatial skills (model making with uncle, knitting with mother, etc.). As the sample group was included in the similar socio-cultural group, no significant differences were observed in the results. Different results can be obtained with different sample groups containing socio-cultural group wealth.

University admission score*:* As the university admission scores of the students were close to each other for the same university, therefore there was no statistically significant result.
Other information from the backgrounds of the students: Referring to Figure 4, experiences such as playing computer games, taking geometry lessons, taking art lessons, and work experiences affecting spatial abilities are mostly absent for the students. Therefore, no

significant result was found between these factors and the PreT result, although it is seen that students have experience in doing sports and especially playing games like puzzle. Medina, B. P. Gerson and Sorby (1998) had found statistical significance in the development of 3-D spatial skills for almost all factors. The existence of this variable may be due to the difference in the years of the research. Medina, B. P. Gerson, and Sorby's research was conducted with 713 students from two universities, in 1997. The socio-cultural changes experienced during this time may have made it possible for students to gain access to factors that provide equal spatial experience.

The Progression in PreT and PostT Scores:

The averages of students' assignment scores during the 14-week course period can be used as indicators for spatial ability progression, besides PreT and PostT scores. Figure 7 presents the assignment performances based on spatial ability factors. Unconditional pass grade of the course is 65 out of 100. It is seen that the average of the assignments per week is over 65.

In Figure 7, it is observed that there is a decrease in the average of the assignments' scores in the weeks 5, 7, 11, 12 and 13, in which SV, SO and MR abilities were integrated. A significant progression was identified on SV+SP, SO, and SR+MR between PreT and PostT results, while no significant progression was found at MR tests. The averages of the assignment scores also support this finding. The reason of the students' having difficulty in making progress in MR ability can be revealed by examining the developmental stages of spatial ability. Level 1 and Level 2 stages of spatial ability develop until adolescence (Bishop, 1978 as cited in Sorby 1999; Mohler 2008), in other words before university education. The Hidden Figures and Hidden Patterns tests that assess SV and SP ability include only Level1 ability (Ilic and Djukic, 2017); therefore, the success of the students in this test group is not surprising. Uttal et al. (2013) state that individuals improve their spatial skills performance by experiencing spatial training from practicing a specific task and taking a drawing class. This study reveals that the ARCH 101, a technical drawing course, contributes to the development of spatial skills in terms of SV+SP, SO, and SR+MR factors.

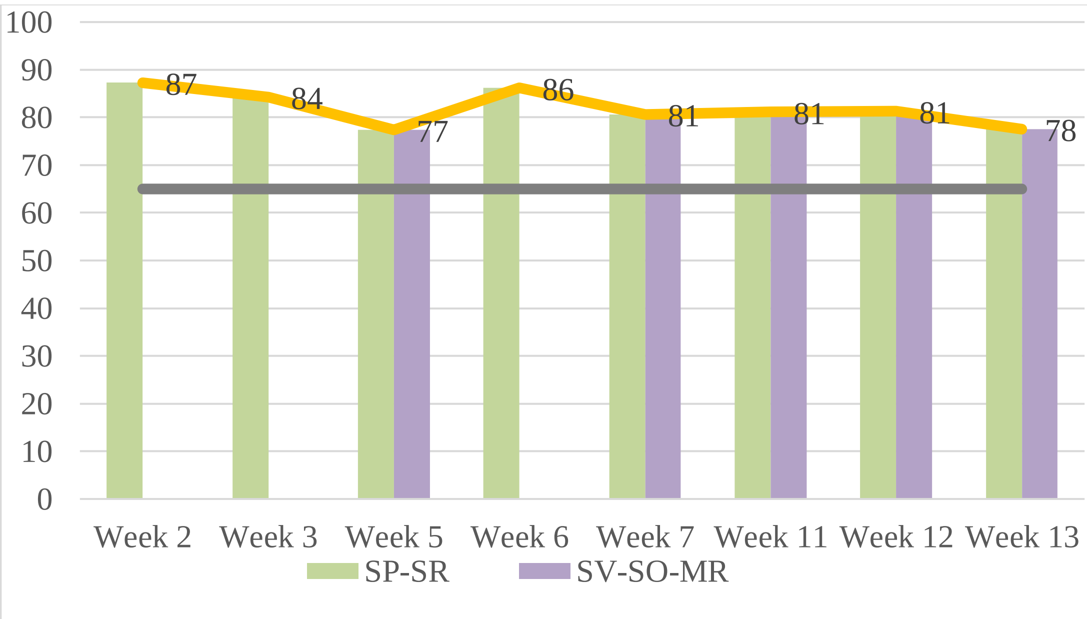


Figure 7. The assignments' average scores in terms of spatial ability progression.

In order to examine the contribution of ARCH 101 course in the development of spatial skills of the architecture students, it is observed that the percentage of the MR factor in the syllabus is similar with SO and SV factors, which have statistically significant progression (Figure 6). No significant difference could be observed in MR factor between the PreT and PostT scores. As a result of research on the investigation of the relation between spatial ability, creativity, and studio performance in architecture education, Cho (2012a) reported that students felt MR the most difficult among the three spatial ability tests (MR, Paper folding and SO).

Baenninger and Newcombe's (1989) research on the role of experience in spatial test performance highlights that the participants who have higher spatial experience use their maximum potential in pre-test so they do not show a higher progression in post-test, on the contrary, the participants who have lower spatial experience have the potential to increase their scores in post-test. In this context, this research was re-evaluated on the basis of pre-test in order to observe the progression between the pre-course spatial ability levels and the post-course spatial ability levels. Almost half of the students (49 out of 96 students) have spatial skills on a 60-80% scale. While the spatial skills of the students with above-average spatial skills progressed at a lower rate, the spatial skills of students with lower spatial skills before the training revealed a higher rate of progression. In this context, it can be said that there is an inverse relationship between PreT scores and skill progression rates. The student groups with low scores in the PreT may not have been sufficiently exposed to the spatial skills experience before the training. Therefore, spatial ability is not only an innate skill, but a skill that can be developed through life-long experiences.

Conclusion

Spatial skill is an important intelligence in architecture as in other STEM disciplines. It is necessary for an architect to visualise, transform, scale, associate and scale a space/design. Architecture students begin their undergraduate education life with spatial skills that have been developed since their childhood. Level 1 and Level 2 spatial skills can be acquired at certain and different levels until university education, and 3rd level spatial skills are taught through various courses within the undergraduate education, especially for professions that need specific spatial skills, such as architecture. ARCH 101 is one of these courses and given in the first semester of its education. In this course, students who are new to university are expected to gain graphic expression and 3D thinking skills, to use appropriate representational media, to develop visual perception and to obtain fundamental design skills. In this study, the contribution of ARCH 101 course to the development of spatial skills of the first semester students is investigated by PreT and PostT research.

Although spatial ability is an innate ability, it is also a skill that can be acquired by learning. Spatial experiences since childhood, such as playing with construction toys or having sketch experiences, can improve spatial skills. Therefore, a questionnaire consisting of factors supporting the development of the spatial skills mentioned in the literature was performed before the research in order to obtain information about the students' spatial experiences. The results of the questionnaire and the scores of the PreT and PostT were examined through SPSS. Statistically progression between PreT and PostT in the context of gender was found as mentioned in the literature. Particularly significant difference between men and female was found at SO progression in PreT and PostT. On the other hand no statistically, significant

progression was obtained through the evaluation of PreT in the context of spatial experience backgrounds. In further studies, different results can be obtained by expanding the sample group of the research under different circumstances.

A statistically significant progression was observed in comparison with the PreT and PostT scores. However, this progression differs in the context of student's ability. In the study it is revealed that the students with lower spatial skills before the training acquired a higher rate of progression compared to the students with higher spatial skills before the training. Considering that the architectural students are in the first of the eight-semester education process, the progression of the students in the course in terms of spatial ability is noteworthy. This result confirms the argument that the ARCH 101 course contributes to progression of the students' spatial skills. The progression between pre-tests and post-tests was found significant with SV+SP, SO and SR+MR tests, while no significant progression was found in MR test. It was also observed that the mean of MR ability did not increase between the PreT and PostT. The average of the assignments' scores of the students also supports this finding. When the spatial skill factors are taken into consideration, it is seen that MR was treated equally with SO and SV in the context of course duration. Although there was enough time for MR in the syllabus, it was observed that students had difficulty in this skill. In further studies, developing the MR skill by updating the curricula in order to progress MR skill and the correlation of spatial skills progression with architectural design courses can be examined.

The researchers hoping to extend and improve upon the present study by including first year architecture students from other universities in the study group.

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Book Review: Re: Research, Volume 1: Teaching and Learning Design

Muratovski, G. & Vogel, C. (Eds.). (2019). *Re: Research, Volume 1: Teaching and Learning Design*. Bristol. Intellect Books.

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Introduction

Published by Intellect, this book, *Teaching and Learning Design*, has emerged from the proceedings of the Re: Research – 2017 International Association of Societies of Design Research (IASDR) Conference at The Myron E. Ullman, Jr. School of Design, in the College of Design, Architecture, Art, and Planning (DAAP), University of Cincinnati. This volume, *Teaching and Learning Design*, is first in a series of seven thematic volumes, each presenting an edited collection of papers on topics as wide-ranging as philosophical frameworks and design processes, to design discourse on business and industry.

In the foreword and introduction to this book, the editors set the context: design research in the United States is still an emerging aspect of design practice and education, and thus far, it is industry that has played the most influential role in embedding research into design practices. The collection of papers is meant to reflect a snapshot of the diverse practices of design and design research as it is currently. The inclusion of a wide range of international perspectives and case studies in this book is refreshing, and there is no dominant Western leaning in its content. This collection of eleven papers by many different authors from across the globe demonstrates the increasing breadth of enquiry that is taking place in design education, and the expanding range of research models applied to the subject.

Teaching and Learning Design is not a practical guidebook to teaching design at university level or an inventory of pedagogical strategies but presents a range of projects and studies that seek to better understand design teaching and develop new models for facilitating learning and assessment. They vary in their depth of theoretical underpinning; some papers place emphasis on the description of specific projects, some of which involving testing/delivery across institutions and countries, or collaboration with external groups including industry.

There are a few observations that are common. Some authors raise fundamental concerns about the rigid structure of primary and secondary education (that do not appear to be limited to particular countries or cultures), and how this early conditioning of students to produce black and white answers to set questions negatively impacts their ability to approach design practice as an iterative process that requires a continuous cycle of development/feedback in order to problem solve. Indeed, the nature of design practice is highlighted in various forms in *Teaching and Learning Design* and discussed in relation to innovation and risk-taking; reflexive practice; inter-disciplinary approaches; and even the impact of having more than one possible

solution leading to learning pressures and stress. Additionally, a few papers highlight the value of the workshop-based format in design education, as well as the benefits of collaboration and industry engagement to the learning experience.

(Referencing note: Numbers in brackets refer to pages in *Teaching and Learning Design*)

'Opening a Design Education Pipeline from University to K-12 and Back', *by Peter Scupelli, Doris Wells-Papanek, Judy Brooks, Arnold Wasserman*
This paper describes a pilot study in the United States that explores how educators might teach K-12 students (the equivalent of primary/secondary education) and university design students to embed design thinking and learning with future foresight. The project evaluates how a university-level Design Futures course (including content, approach, and teaching materials) can be adapted for use in K-12 Design Learning Challenges. The paper describes the K-12 design-based learning challenges/experiences developed and implemented by the Design Learning Network. This is a descriptive piece with some interesting ideas for cross-level exchange, involving different demographic profiles of students.

'Re-Clarifying Design Problems through Questions for Secondary School Children: An Example Based on Design Problem Identification in Singapore Pre-Tertiary Design Education' *by Wei Leong, Leon Loh, Hwee Mui, Grace Kwek, Wei Leong Lee*
This study is based on an observation that secondary school students in Singapore often define design problems in their coursework at a superficial level 'due to various reasons such as lack of exposure, inexperience and the lack of research skills.'(25) The project involved the use of questioning techniques to develop critical thinking, enabling pre-tertiary students to improve their understanding of design problems. Through critique of their thinking and approaches, more effective design solutions were generated. The study used student design journals to document processes and reflection/ evaluation at each stage of development. This qualitative approach adopted captures the learning journey from design problem identification to proposed solutions.

'Surveying Stakeholders: Research Informing Design Curriculum' *by Andrea Quam*
This paper proposes the necessity of using surveying methods as a research tool to define the content and structure of the curriculum, specifically in relation to design education. According to the author, 'neither the creation of design curriculum, nor the revaluation of existing curriculum is well documented.'(49) This paper presents the use of a broad survey to assess existing curriculum at Iowa State University in the United States, which reflected the needs and perspectives of the program's diverse stakeholders from students and staff, to industry professionals, in relation to the design curriculum. The collection of data and analysis of the outcomes of the survey informs curricular decision-making; the transparent and inclusive approach of the survey enabled 'the reduction of faculty bias and speculation in the process.'(50)

New Challenges when Teaching UX Students to Sketch and Prototype *by Joep Frens, Jodi Forlizzi, John Zimmerman*
This paper argues that UX students sketch and prototype differently in comparison to other design students, and that changes in the field requires a change in educational approaches,

whereby sketching and prototyping is regarded as a continuum, an ongoing process of 'double loop learning'. (62) Three new challenges highlighted include new computational design materials; new maker tools; and changes within the tech industry. These challenges were explored through examples with their students, and steps forward suggested in design education. These are proposals for a contemporary approach to teaching UX, whereby design education has somewhat lagged behind industry practice and application.

How to Teach Industrial Design?: A Case Study of College Education for Design Beginners *by Joomyung Rhi*

This paper presents the way a Korean university structures a course on industrial design, describing the process and outcomes of the first stage of industrial design education through an 'autobiographical' method (78). According to Rhi, this type of autobiographical research promotes positive reflection and allows for greater refinement of learning and teaching approaches over time. Highlighting the importance of self-reflexivity, open dialogue and exchange of ideas between tutors and students, the curriculum is delivered via studio sessions which are framed around two linked projects, involving an increased level of complexity as students develop their concepts. Teaching and learning entailed a 'continuous task-feedback cycle process' (89), where design concepts, principles, processes and methods etc., were embedded in weekly sessions. Rhi suggests that through the autobiographical way of looking at the class, the researcher was able to reflect on the strengths and weaknesses of the approach to learning and teaching, and to draw implications for future improvement.

Preliminary Study on the Learning Pressure of Undergraduate Industrial Design Students *by Wenzhi Chen*

This study explores the issues causing learning pressure in undergraduate industrial design students in Taiwan, as well as their pressure management strategies employed to cope with these pressures. Chen states that the nature of design development entails a process of 'learning by doing'(92) and the significant amount of time required to solve problems creates time management pressures in meeting assignment deadlines. The study proposes that the requirement to solve real design problems creates heavy working loads which may in turn lead to learning pressure. It also explores ways in which these students manage learning pressures, such as engagement in leisure activity and problem solving.

Whilst the sample surveyed for this research focused on industrial design undergraduates, the outcomes and analysis may be applicable to any student (i.e. the learning pressures described can be attributed to most UG students) and the specificity of the study to industrial design remains unclear.

Rewarding Risk: Exploring How to Encourage Learning that Comes from Taking Risks *by Dennis Cheatham*

This design research project was undertaken with Miami University Graphic Design students to discover curricular formats that could encourage students to risk failure 'by attempting innovative outcomes that exceed prescribed learning objectives.' (106)

The trial-and-error process of defining problems and exploring possible solutions is iterative, where ‘failures’ are part and parcel of the developmental process. Cheatham states that primary and secondary education in the United States is ‘prescribed and linear’ (105); hence, students are conditioned to find black/white answers from early education, and this is limiting them from undertaking risks and finding innovative design outcomes. He also proposes that a focus on formative (instead of summative) assessment as a significant part of the learning process may encourage increased risk taking. Citing student motivation when developing learning experiences as an important factor, this awareness could help students make the transition to practicing design as an iterative process fraught with risk, which will in turn lead to more innovative solutions.

An Analysis of the Educational Value of PBL Design Workshops *by Ikjoon Chang, Suhong Hwang*

Carried out over 2 weeks in 2017 at Korea’s Yonsei University, the purpose of this study was to design and deliver design workshops based on project-based learning (PBL) and to examine their educational value for students.

The workshop format encourages direct and proactive participation from students; and this study involved a workshop which was composed of eight teams of students from three countries, including Korea, China, and Japan. An important element of the workshop was to connect the participants with businesses, which is also an important component of design education. The questionnaire conducted at the end of the workshop reflected the ample educational value of the workshop format, even though there was a less favourable response in relation to industry input, which requires further exploration and analysis.

The workshop format in learning and teaching ‘is synonymous with communal education and team-based education.’ (118) In contrast to traditional teaching approaches that primarily rely on the delivery of information to participants (such as in a lecture theatre), workshop education relies on engagement and participation.

Collaborative Design Education with Industry: Student Perspective by Reflection

by Nathan Kotlarewski, Louise Wallis, Michael Lee, Gregory Nolan, Megan Last

This paper proposes that student reflection on academic and industry collaborative projects can enhance student’s understanding on the design process to solve live industry problems. The study is based on a 2017 learning by-making (LBM) unit, where Furniture, Interior and Architecture students in the School of Architecture and Design, at the University of Tasmania, Australia, collaborated with Neville Smith Forest Products Pty. Ltd., a local Tasmanian timber product manufacturer who stockpiles out-of-grade timber that has limited market applications, to value add to their out-of-grade resource in this LBM unit. Through a series of design challenges, observations of industry practice and access to timber materials/supplies, students were exposed to live industry problems and opportunities to build professional design skills.

This study presents how student reflections influenced their design process as they responded to design challenges to address an industry problem. This was illustrated by incorporating Valkenburg and Dorst’s (1998) reflective practice framework against student’s transformative learning process development.

Collaborative learning environments bridging industry and academia expose design students to live industry problems that enhance their professional development and build confidence to approach design opportunities in the real world, where outcomes produced need to be feasible and commercially viable.

Interdisciplinary Trends in Design Education: The Analysis of Master Dissertation of College of Design and Innovation, Tongji University *by Lisha Ren, Yan Wang*
Explored within the context of historical Chinese design education, current design education at Tongji University is explored, based on an analysed sample of 458 Master theses from the College of Design and Innovation between 2010–2016. Through the coding of subject classifications, quantitative analysis and content analysis, the interdisciplinarity of education is explored from the two perspectives - the extent of cross-disciplinary practice; and the relationship between different cross-disciplinary directions.

The authors posit that interdisciplinary design is crucial in solving complex social problems and promotes the development of social innovation. Since the 1980s, China's rapid economic growth and the demand for design professionals increased dramatically, leading to the large-scale development of design education as well. In order to deal with modern day challenges, a more open and inclusive understanding of design is required; where a series of emerging design areas that are mostly interdisciplinary and innovative, such as interactive design and service design, have been spawned. Following the lead of other countries, China has gradually established interdisciplinary laboratories and formulated its 3D 'T-shaped' Design Education Framework (143), developing interdisciplinary knowledge, integration of innovation and design methods.

The outcomes of the study reflected a great degree of 'interdisciplinary performance'. (151) Furthermore, the interaction of design disciplines with non-design disciplines is also reflected in a significant number of Master dissertations, especially the integration between industrial design and environmental design with psychology, materials science, behaviour science and other relevant disciplines.

From ANT to Material Agency: A Design and Science Research Workshop *by A.L. Renon, A. De Montbron, A. Gentes, J. Bobroff*
This paper provides a study of a design workshop that investigates a complex collaboration between physics and design. Using methods and concepts of the Actor Network Theory (ANT), the study explores the ways student projects were developed over time and through a diversity of inputs and media. Employing a semiotic and pragmatic approach, the analysis observed three operations ('aesthetical formations') that appear to be key to understanding design practice: translation, composition, and stabilization.

The researchers state that the radicality of the experiment lay in the fact that 'fundamental physics is intangible in essence and the starting point of the design project is therefore abstract. However, the designers took into account and invested the scientific material, which became both a tool and a function for exploration.' (167) Material agency inherent in any design process does not refer only to tangible objects, but is 'made of iconic, technical and semiotic dimensions.' (167) Students draw from a range of associations in the design process and these

'aesthetical formations'(157) as described by the authors highlight 'not only a personal, subjective experience but also a cultural and historical situation, as well as a social space of communication.' (168)

Conclusion

In *Teaching and Learning Design*, authors discuss the nature of contemporary problems and propose teaching and learning strategies in the context of an increased need for interdisciplinary engagement and technological change. It is interesting to note the similarity of some of these challenges as identified by authors from different countries, and also the variation in educational frameworks and processes, for example, curriculum design. Although the wide range of studies presented mean the book may not be universally relevant to all design educators, the ideas offered are nonetheless food for thought.
Overall, the volume as a whole captures the wide range of work happening in design education today, highlighting a few exciting developments in approaches to teaching and learning.

References

Valkenburg, R., & Dorst, K. (1998). The reflective practice of design teams. *Design Studies*, 19(3), pp. 249–271.

Book Review: Pedagogy for Technology Education in Secondary Schools

Williams, P. J. & Barlex, D. (Eds.). (2020). *Pedagogy for Technology Education in Secondary Schools.* Switzerland. Springer Nature. https://doi.org/10.1007/978-3-030-41548-8

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Reviewed by Liam Anderson, Trinity School, Newbury, UK and Alison Hardy, Nottingham Trent University, UK

Williams and Barlex have edited an authoritative book about pedagogical practices in design and technology education. The subtitle states that it provides 'Research Informed Perspectives for Classroom Teachers' and with this in mind our primary criterion for reviewing this book is: Is the book suitable for teachers? With secondary criteria: Will it contribute to their work in the classroom and thinking about their practice? Is it accessible to this audience? Does it include new and challenging ideas?

Williams' opening chapter sets out a clear context and direction of the book but if the reader overlooks this chapter they may miss the book's intent. The introduction is helpful and clearly establishes what this book is about. Williams' synopses of each chapter will help readers understand the 'bigger picture' and provides an entry route into some of the new and complex ideas explored later in the book.

To review the book, one of us selected 3 of the 16 chapters that appeared from the title to be particularly relevant to his classroom practice: Kay Stables' chapter, *Signature Pedagogies for Designing: A speculative framework for supporting learning and teaching in design and technology education;* Torben Steeg's and David Hills-Taylor's chapter, *Pedagogy for Technical Understanding;* and John G. Wells' and Didier Van de Velde's chapter, *Technology Education Pedagogy: Enhancing STEM learning.*

Stables' chapter on *Signature Pedagogies for Designing* provides a pragmatic and accessible summary for teachers of design pedagogies. The pedagogic design tools introduced in the chapter are referenced closely to the practice of the subject of design and technology, grounded in evidence-based research of others throughout, thus being a pertinent and essential read for those involved in classroom practice.

The glossary included at the end of the chapter gives comprehensible descriptions of each tool, detailing what these are and how they can be applied in teaching and learning, with links and references for those who may wish to explore these ideas and tools further, which is easy to digest. An illustration of this is Stables' mention of the pedagogy of 'body storming', where she gives an uncomplicated description of the tool being 'it involves creating a physical situation through which a learner can experience specific needs, such as poor vision and lack of mobility' (p.115). Stables goes on to exemplify how this could be used in practice in the classroom to

'simulate user testing of models and prototypes as their [students'] design ideas evolve'. All pedagogies described in the glossary are presented in this same accessible format. This table of pedagogical tools is useful, and whilst the pedagogical tools listed are somewhat limited, they are a strong starting point for classroom teachers to prompt thinking and further exploration. Therefore, this chapter met Stables' aim of 'speculating on a fresh way of considering the nature of a pedagogic framework' with 'an ambition for teachers to implement the approach proposed' (p.114).

Steeg and Hills-Taylor's chapter concentrates on the teaching of 'technical' aspects of design and technology teaching – 'the elements of a technology (e.g. aspects of electronics or structures) that together make it work' (p. 177). Through the lens of factual, procedural, conceptual and tacit knowledge, Steeg and Hills-Taylor present a meticulous dissection of what is meant by technical 'knowledge' and how it can be delivered through selecting effective and appropriate pedagogies. Their discussion provides a timely perspective in light of the current discussions around knowledge-rich curricula in schools. Steeg and Hills-Taylor examination of forms of knowledge challenges teachers to think about how we can effectively deploy these pedagogical methods by contemplating about what knowledge is being taught. They give helpful examples of how their ideas might be used in the classroom through the inclusion of case-studies and reflection sections on the success of these approaches with students in the classroom. For example, Steeg and Hills-Taylor make their discussion of teaching technical knowledge highly relatable to the English design and technology classroom with particular reference to teaching technical understanding of the scientific elements of the new post-14 specifications being taught in England and providing in the chapter three pedagogical approaches.

Whilst Steeg's and Hills-Taylor's chapter will encourage teachers to consider what knowledge they are teaching and how this might be taught, the question is - are the pedagogical approaches explored in the chapter new or novel and should the authors have considered how the approaches they discuss related to current lexicon, such as knowledge organisers' similarity to chooser charts. However, what this chapter importantly provides is an opportunity for teachers to really consider what forms knowledge are used in designing these pedagogical approaches and this will prove extremely useful in creating effective teaching resources.

Wells and Van de Velde's chapter on pedagogy for *Enhancing STEM Learning* sets a great deal of background of what STEM (science, technology, engineering and mathematics) is, but seems somewhat more distant from how this might be taught using different pedagogical tools by design and technology teachers. Wells and Van de Velde provide an excellent background insight into the development of STEM learning and what this interdisciplinary concept consists of and has a clear focus on how STEM could be integrated into the curriculum. However, this chapter would have benefitted from some more tangible approaches to interdisciplinary teaching of these subjects. Wells and Van de Velde discuss how approaches such as problem scenarios and design challenges could be used for teaching STEM learning with some good examples of student work from teaching of STEM but it is unclear how novel this perhaps is from what many schools already do. However, this chapter will be useful for teachers new to teaching the interdisciplinary learning of STEM.

We provide this critique of three chapters as a taste of the other chapters. The other 13 are similar in that they provide teachers with thought provoking ideas and suggestions that could influence their classroom practice. A few chapters include vignettes intended 'to illustrate the discussion and prompts for reflection, which can be used by the reader to guide their contemplation' (p.1) and where these appear, they are helpful.

Having read the book, we think *Pedagogy for Technology Education in Secondary Schools* is a timely addition to the growing literature available for teachers to peruse and expand the knowledge, thinking and ideas about design and technology pedagogy. However, this endorsement comes with some caveats.

With many teachers subscribing to the 'What Works' movement and conducting research into their own practice, there has been an increase in the demand for books about pedagogical ideas and practices for design and technology. However, if that is what readers are looking for in this book, they will be disappointed. That is not to mean that this book is disappointing – far from it – but rather that it is a book in the long tradition of publications from Springer about technology education, in that the contributors sometimes write in a style that makes it challenging for non-academics or teachers, with little time to sit and digest the whole intent of a book, to access. So, this is where the unusual 'Synoptic Review', written by the second editor David Barlex, comes into its own. Barlex summarises and offers his own perspective on each chapter, which we think teachers will find helpful in exploring the potential the perspectives presented could have on their classroom practice. But we wondered if these summaries would have been better placed immediately following the chapter and possibly co-produced with the chapter's authors.

There are two other topics that need addressing: the price and diversity of authors. Firstly, to date the book's price point has unfortunately caused more discussion on social media than the content. As teachers are wanting to know more about research in the field a book retailing at over £85 for an e-version is prohibitive to many and potentially makes this an exclusive publication with only institutions purchasing a copy, not individuals. Publishers, such as Springer, are known for their scholarly books and command a high price, although the justification for this is not necessarily appreciated by classroom practitioners. So, the decision lies with editors and authors – do you write for a scholarly publisher but thereby excluding those who would gain most from the content or do you write for publishers whose price point is more accessible to the intended audience but where the academic kudos may be less? We raise these points not to criticise the editors instead to add to ongoing debate about accessibility to new thinking as part of an inclusive community. Second, with contributors from a variety of jurisdictions the book goes some way to decolonizing the design and technology curriculum and field due to the locality of the 24 authors, although we note they are predominately Western, white and male. Addressing this diversity will take time and future editors will need to be more mindful about how their books ensure that black lives do matter.

To conclude we return to our criteria for judging this book. Yes, the book is suitable for teachers particularly if they read the opening and closing chapters first. Yes, it will contribute to their work in the classroom and thinking about their practice as we show with our evaluation of 3 chapters (rest assured - the others do the same). If we were scoring its accessibility, we would award 3 out 5. The range of topics means there is something for everyone, but the style and

structure could be off putting to some; the cost excludes some as does the representation of people of colour and gender. Finally, yes - there is much here that will challenge accepted practice. This is a useful book for institutions to purchase.