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Shared Insights: Removing barriers to understanding in design and technology education

Prof Kay Stables, Goldsmiths, University of London, UK

Dr Erik Bohemia, Loughborough University, UK

The world over there seems to be increasing pressure on educators – pressure from budgets, pressure from policies, pressure from schemes of accountability, whether for teaching, researching or pastoral aspects of the role of an educator. Dealing with such pressures brings with it a reduction in time to get on with the practice of teaching –whether we are working with early learners, teenagers or undergraduates. And the knock-on effect from this can be even more reduction in time for reflecting on our practices as educators. Pressure of time can stifle innovation, collaboration - from doing anything beyond addressing the immediate with safe solutions from past practices, staying in our comfortable silos, whether they are boundaried by the age groups we teach, the disciplinary aspects that we teach, the national and regional contexts we teach in.

The DATE journal took a brave decision some ten years ago to disrupt some boundaries in design and technology education. The journal's antecedents date back to the 1967 with the publication of the first issue of *Studies in Education and Craft*, a journal centred almost exclusively on UK mainstream primary and secondary schooling. There is an evolutionary path to the current *Design and Technology Education: An International Journal* but the international, age, stage and disciplinary diversity of articles now published in the journal shows a step change in the audiences the Journal now communicates with. As editors, there is a constant question – does the academic working with postgraduate design students stop, read and learn from an article focused on research with the very youngest children in our education systems? And is this stepping beyond reciprocated. Can we learn from each other?

This final issue of Volume 22 is as varied as the journal has become – authors representing: Canada, England, France, New Zealand, Norway, Sweden, Turkey, and Wales; compulsory, undergraduate, pre-service and in-service education. But the overarching theme of all articles is learning. Taken together, in many ways the articles provide insights that can enrich understanding of design and technology education across the diversity, shared insights across barriers. From an article about oral assessment feedback with undergraduates whose messages are equally relevant to oral feedback with young learners, to three articles from different contexts, looking at dimensions of 21st Century skills, that between them provide a rich collection of insights, to two articles that open up questions, insights and possibilities around Interdisciplinarity that have broader messages that inform pedagogical approaches, not least in the context of STEM, this issue provides reflective nourishment.

So, we encourage readers to pause, step over boundaries, explore the potential of sharing insights from beyond.

With no departure from the tried and tested, Richard Kimbell provides another of his reflections, this time giving some thought to the ebb and flow of tides. In *Bow creek and some mental arithmetic,* he ponders on some technological possibilities of tidal waters, the impetus they have provided and continue to provide for innovation. This sets him to reflect on some of the exciting project work he has witnessed over the years, reinforcing his conviction of the value of embedding design and technology projects in rich, thought provoking contexts – an important issue for many and particularly timely in the current schools' context.

Moving to the research section of the journal, this issue provides insights into formative assessment, maker based education, 21st Century skills, pre-service education, teachers' perceptions and perspectives, and pedagogic approaches and challenges to interdisciplinary settings.

Kristine Hoeg Karlsen, Østfold University College, Norway contributes, *The value of oral feedback in the context of capstone projects in design education*. This first article focuses on formative assessment with undergraduate design students, in particular the use of oral feedback - what students find useful and the conditions that need to be met to support the feedback being useful. Research was undertaken with final year students working on their capstone projects. Open ended in-depth interviews were conducted linked to a four-dimensional framework: the form of the feedback, the focus of the feedback, the purpose of the feedback in terms of the learning potential and temporality in terms of feed-back and feed-forward. Feedback was initially coded using the binary of useful or useless and then analysed through the lenses of the four dimensions. Feedback was more often seen as useful than useless, but what emerged through more detailed analysis was the sequence of dialogue – an example given illustrates how a student found feedback helpful that started with a question from the tutor, followed by a judgment and then a correction and concluding with a suggestion. An important condition was a student's perception of the tutor's comments as trustworthy, based for example on their knowledge and experience or the level of engagement with the student's work. The article provides fascinating, detailed insight into the range of aspects that influence the effectiveness of oral feedback, providing much to reflect on for anyone working with students on design projects.

The next three articles focus on the development of 21st Century skills, two in the education of pre-service teachers and the third exploring teachers' perceptions.

In *Creativity assessment in the context of maker-based projects*, Benjamin Lille, Université Laval, Canada, and Margarida Romero, Université Nice Sophia Antipolis, present research into the links between learning through making and the development of creativity. The article draws from #SmartCityMaker, a research project that approaches learning-by-making through a co-designing and co-constructing pedagogical model and that includes digital resources that combine with physical resources to create smart city models. The participants in the research were pre-service pre-school and elementary school student teachers. The students worked in teams and were assessed first on an individual basis, focusing on their process of creating an urban building model. The second assessment was team based and focused on pedagogical creativity in developing a resource that addressed an educational issue. Assessment was qualitative and formative, drawing evidence from team-based diaries and learning journals, and made use of a rubric-based tool. This enabled assessment of creativity and design thinking in both building models and in designing pedagogic activities, alongside assessing knowledge such as coding and robotics. They argue that maker-based pedagogical design projects support creativity without sacrificing knowledge acquisition. This is valuable learning for pre-service teachers.

The second article comes from Paul Snape, University of Canterbury, New Zealand. In *Enduring Learning: Integrating C21st soft skills through Technology Education*, Paul provides a scholarly review of 21stCentury skills linked to learning by doing in authentic contexts. A particular emphasis is on the importance of developing enduring learning and the New Zealand Technology Education curriculum. The article highlights the iterative active and reflective nature of the learnings. It also highlights a strength provided through Maori culture and the affordance of focusing on spirituality, reciprocity, sharing knowledge, respect, tolerance and understanding. As with the previous article, there is a clear message about the potential for balanced development of knowledge acquisition and high order 21st Century skills and the importance of this understanding for pre-service teachers

The third article providing insights into 21st Century skills focuses on practicing teachers' perceptions. In *Design, system, value: The role of problem-solving and critical thinking capabilities in technology education, as perceived by teachers*, Patrick Schooner, Charlotta Nordlöf, Claes Klasander and Jonas Hallström, Linköping University, Sweden, focus on the under-researched area of teachers' views on teaching 21st Century skills. The research explores the views of twenty one teachers in the Swedish compulsory sector, through in-depth qualitative interviews. Analysis identified three different approaches to developing these skills, a design approach focusing on design and construction, a systems approach focusing on the complex and network aspects of technology and a values approach, concerned with social and other implications of technology. While allowing for these different approaches to be identified, what was also apparent was how teachers used different approaches at the same time, using an integrative pedagogy. These findings indicate a contrast with other research, suggesting that much teaching is de-contextualised design and make activities. The research also indicates more complex aspects, for example the decrease in focus on problem solving from designing and making, though the systems approach to the values approach, and the reverse being evident for critical thinking, and the implications this has for teacher development. The research has a wider message, of going beyond pedagogical rhetoric, showing a value for research that focuses directly on the practices and beliefs of classroom teachers.

The final two articles look at the challenges and benefits of working across disciplines.

In, *Action Reflected and Project Based Combined Methodology for the Appropriate Comprehension of Mechanisms in Industrial Design Education*, H. Güçlü Yavuzcan and Damla Şahin of Gazi University (Turkey) focus on the challenge of introducing engineering knowledge into industrial design courses in Higher Education when the pedagogy is based on traditional verbal lectures. The research presented is drawn from a study where an alternative model, drawing on Kolb's work on learning cycle and learning styles, focused on experiential, project based learning formed the basis of the pedagogic approach. The engineering knowledge at the core of the project was that of mechanisms. Drawing together theoretical and practical knowledge, including 3D computer modelling, the students were presented with an action learning team challenge of designing mechanical games. The outcomes illustrated the value of using visual approaches with industrial design students alongside concrete learning and hands-on modelling, including 3D modelling, embedding the learning of conceptual knowledge in activities where students were 'doing' and applying. A valuable dimension of the article is the contrasting of two distinctly opposed pedagogic approaches, one more typical in engineering and one more typical in industrial design, at a time when technological developments are drawing extensively on both disciplinary areas, particularly with the increased focus on integrated STEM education.

Last, but certainly not least, is an article showing the positives of interdisciplinary experiences. In *How to frame the un-known? The odd alliance of design and "fundamental physics" in a design school*. Annie Gentes, Anne-Lyse Renon (Telecom ParisTech) Bobroff Julien (LPS - Univ. Paris Sud CNRS) France, provide insight into the increasing importance of Interdisciplinarity and the impact of using science in a productive way in the education of design students. The article focuses on how design students can engage with interdisciplinarity through co-design and dialogue with other disciplines. The authors aimed to take 'designerly ways of knowing' into the realms of 'expansive learning'. The project brings together design educators with a fundamental physicist. The research focuses on a framework with five properties or dispositives: affective, cognitive, reflexive learning, economics and political and is based on a series of workshops themed on fundamental physics (superconductivity, quantum physics, light and optics) each of which formed the inspiration for students to create a design project. Drawing on data gathered through post-hoc interviews, each of aspect of the framework is illustrated, indicating its value for interdisciplinary projects. An important message from this research is, while they might increase their understanding of science, the real significance is how students can become better designers, dealing with complexity and uncertainty, by designing in a context of 'odd alliance' across disciplines. This message has been present in the literature for more than forty years – this article provides a strong example of learning this through practice.

Issue 22.3 concludes with two book reviews, both focusing on new edited collections from the *Contemporary Issues in Technology Education* series, published by Springer. In the first review, *A new paradigm for design and technology education?* Matt Mclain reviews *Critique in Design and Technology Education*, edited by P. John Williams and Kay Stables. Jason Davies then provides the second review, this time for *Contemporary Research in Technology Education*, Edited by John Williams and David Barlex.

We hope that you enjoy this issue of the Journal. As always, we welcome comments and questions on the Journal, and invite all interested to submit articles for consideration to be included in future issues.

Bow Creek and Some Mental Arithmetic

Prof Richard Kimbell, Goldsmiths University of London

I have a small boat that I enjoy poddling about with in estuary waters, and my favourite is the Dart estuary in Devon, between Totnes and Dartmouth. It is all tidal and at low tide throughout the whole length of the estuary there is an uninterrupted view of mud. Whether this is preferable to high tide seems to vary depending on my mood at the time. In relaxed and reflective mode there is something deeply soothing about vistas of mud – with wading birds, moored boats sitting, beached, beside their unnecessary anchor cables, and with the occasional tree-root and other flotsam half embedded in its squishy embrace. At high tide of course it is all quite different; full of life and energy and action.

One of the inevitable truths of estuary boating is that you cannot mess with the tides. As King Cnut discovered in the 11th C, they are not open to negotiation. They go up and down like clockwork, just as the tide tables predict. So its good advice not to explore on a falling tide. If you sail up a side creek on a falling tide – and stick on the mud – you are there for many hours until the falling tide reaches the bottom and then the returning tide lifts you off. So my exploration of new creeks and by-ways is always conducted on a rising tide. Then if you get stuck … you wait 10 minutes and the boat just lifts off again. I was planning to sail into Bow Creek – which is notoriously shallow but with a winding deeper water channel. And as I approached the entrance I knew there was not enough water to attempt the passage. I can't say that it was too much of a problem however, because all I had to do was drop anchor and break out a beer while I read a book and waited for the flooding tide. An hour later I was astonished to read on my echo-sounder that I had risen 2.5 ft (its an old machine) and there was more-or-less enough water to make the trip. What took me by surprise was partly how quickly it seemed to have risen but mostly that it had happened almost surreptitiously … in complete silence, lifting my ton and a half of boat without so much as a quiver.

It was at that point that I started to do a little bit of mental arithmetic. Bow Creek is more-or-less 2km long and (say … on average) 100 m wide. So the water area is something like 200,000 sq metres. If I had waited just a few minutes more, the rise would have been 1m, so in that time 200,000 cubic metres of water flowed into Bow Creek. There are more-or-less 200 gallons in a cubic metre, so the flow in an hour amounted to 40,000,000 gallons. All in silence … and all free. What would the world be like if we had to pump it?

When I got home I did a bit of Googling and discovered that the Guinness world record water pump (Pentair Fairbanks) can move 60,000 litres /sec, which is 13,333 gallons / sec, or 800,000 galls / min, or 48,000,000 gallons / hour. So this mega water pump could have just about filled Bow Creek at the same rate that the tide achieved. The only snag being that it needs a massive engineering infrastructure to make it viable and it won't do anything at all unless fed by 4,000 kW of power. Neither of these requirements is entirely compatible with the tranquillity and the sheer delight of Bow Creek.

Whilst huge engineering infrastructures can be made to harness tidal forces, the current trend seems to be towards smaller-scale, user-centred power generation. It's a slightly different take on one of my Mum's favourite sayings … look after the pennies and the pounds take care of themselves. So I started to wonder about using the power of the tide locally – on my boat. The force of it is really fearsome. As the rising tide sweeps up the English Channel (and floods into the Dart at Dartmouth and hence up into Bow Creek) it flows at a prodigious rate … 5 or 6 knots … faster than you can walk. Then it flows back again into the Atlantic at the same frenetic pace. East-bound, west-bound, back and forth, endlessly. If you fell overboard, only an Olympic swimmer could hope to get back aboard. Most of us would just be swept away. There must be a way to harness such power from on board the boat – if only to top up the batteries that are so important to life on board. It's just a matter of 'how-to', and surely we are good at that in design and technology?

But of course this would only work when anchored out in the channel flow. When moored at the quayside the tide provides very little flow – just lots of up and down movement. But grandfather clocks are driven by just a chunk of lead – maybe 2 or 3 kgs – falling over a distance of about half a metre. And they can keep all that clever clockwork ticking over for a week. My boat – about 1.5 tons – travels up and down by 4 metres every 6 hours. The photo is of my boat at Bosham quay at mid-tide, having fallen by 2m and with a further 2m to go down to the mud. Once again, just imagine the power that could be generated if a suitable arrangement could allow the boat to rise and fall within the constraints of an energy-extracting harness. And just a few miles down the coast in Southampton, the Queen Mary 2 is going up and down at the same rate. The big difference being that it weighs in at 150,000 tons. No-one could persuade me that there is not a significant amount of energy to be harvested from such colossal forces.

All of this thinking about things that don't yet exist – but could - reminded me of projects that I once examined as part of the old Oxford exam board (now absorbed into OCR). It was not uncommon for schools in sea-settings, where the students were often sailors of fishers, to produce sea-based projects. A lobster pot was the focus of one such, since it is typically marked by a floating buoy and the lobster can so easily be illegally lifted by any passing boat. The imaginative solution involved a system that enabled the buoy to pop to the surface just as the owner came around to check the pots. Another – in Cornwall – was by a sailor who had a boat moored off-shore that always had to have rain-water bailed out before he could use it. His solution was to build a pump powered solely by the rocking of the boat; a really clever solution that kept the boat constantly dry. Both were entries in the Schools Design Prize, a sadly lost competition that used to be run by the Design Council. One of the reasons that those projects provided such good examples of designing was, I suspect, due to the matter of context. Activities on the sea provide a very particular context with some very special requirements and limitations. And most of the customs and practices in that environment are driven by tradition. This is rich territory for a design-eye.

Teachers commonly note that their most critical job is to help learners to find the right project, and some have developed variants of an approach that might be called *contextual shift*. This involves deliberately placing learners in contexts that are unfamiliar – and allowing them to wallow in them for a while to see what their design-eye can discern. A school specialising in teaching blind children …. or a fish-farm for raising salmon/trout fry…. or a travelling theatre company. Each has so many special requirements – and it's a pound to a penny that no designer has ever spent time observing in detail what goes on, and thinking about how life might be made better for them.

The challenge of *context* as the source of good design tasks is so critical to the success of projects, that D&TA has produced a set of resources to help teachers to manage it. The approach - broadly – is to see the engagement with context as existing at three levels. At the fully open level, being submerged within a context may produce insightful project opportunities. At a more constrained level, learners' attention might be focused on a particular aspect of a context, for example the *storage* issues for a travelling theatre. And at a yet more specified level, particular tasks can be proposed that can be seen to emerge from a context. There are of course pros and cons with each, and the D&TA resource is a valuable guide to help teachers to navigate the territory. (https://www.data.org.uk/shop-products/iterative-design-in-action/)

Meanwhile, back in Bow Creek, the tide has flowed out again and I'm stranded on a mud-bank. Wouldn't it be good if I could walk across all this mud without sinking in? Hmmm… I wonder if….

The value of oral feedback in the context of capstone projects in design education

Kristine Hoeg Karlsen, Østfold University College, Norway

Abstract

Research frequently reports student dissatisfaction with feedback in higher education. Large class sizes and modularization challenge teachers in providing useful feedback. Most of these studies have investigated student perceptions of written feedback in coursework, and few attempts have been made considering feedback in face-to-face contexts such as bachelor's degree projects. This study aims to enrich our understanding of students' perception of feedback in the context of supervision of bachelor's degree projects using Karlsen's (2015) PLUS model to systematise factors that help improve their utilisation of feedback in learning. Qualitative interviews were used to collect data from two bachelor student cohorts doing their projects as part of industrial design programmes and computer science at a mid-sized Norwegian university college (n=28). Results indicate that students generally find teachers' feedback more useful than useless. In addition to the students own attitudes towards assessment, they report that how they perceive the supervisors' trustworthiness matters when utilising feedback.

Key words

types of feedback; capstone projects in design; formative assessment; supervision; learning; students' responses to feedback.

Introduction

Feedback is the basis of formative assessment (Black, 2008; Sadler, 1989) and is central to higher educational processes (Ramsden, 2003). It is a complex phenomenon designed for various pragmatic and epistemological purposes, depending on the learning environment (Poulos & Mahony, 2008). Recently, in higher education, a shift is taking place from a cognitivist view of feedback to a so-called co-constructivist and sustainable perspective, emphasising the dynamic and iterative nature of learning (Evans, 2013; Boud & Soler, 2016; Ajjawi & Boud, 2017). In the co-constructive perspective, feedback is an integral part of learning and is defined as 'an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition' (Pintrich & Zusho, 2002, p. 250, cited in Carless, Salter, Yang & Lam, 2011, p. 396). This study examines how design students at a mid-sized Norwegian university college reflect on the utility of teachers' feedback in the context of capstone project supervision in design education.

Improving feedback is a central goal of the Norwegian Quality Reform[1] initiated at the beginning of the 2003 academic year to align Norwegian higher education to the Bologna process. The reform brought many changes to educational institutions in Norway, including a reinforced focus on formative assessment. After the reform, students have consistently confirmed that they appreciate being followed up closely, but give low scores when assessing the quality of the feedback they receive (Aamodt, Hovdhaugen, & Opheim, 2006;

[1] White paper/ Official government-issued report, 27 (2000–2001)

Bakken, Damen, & Keller, 2015; Damen, Keller, Hamberg, & Bakken, 2016). International student surveys, such as the Australian Course Experience Questionnaire (James, Krause, & Jennings, 2010) and the British National Student Report (HEFCE, 2010), show similar results. Students' dissatisfaction with feedback could be due to many factors: teachers may have less time to give individualized feedback because of growing class sizes (Hounsell, 2003); There may be conflicts between the many roles that an academic teacher must manage (Tuck, 2012); The modularisation of study programmes may impend longer feedback cycles (Hounsell, 2003; Robson, Leat, Wall, & Lofthouse, 2013). Other factors reported in the literature of why students find the feedback they receive wanting, is that the students themselves are not capable of making good use of feedback (Elwood & Bode, 2014; Värlander, 2008; Winstone, Nash, Rowntree, & Parker, 2016). There is little reason for teachers to invest in giving feedback if students do not consider the feedback worthwhile. The students' positive attitude towards their feedback is necessary for developing sustainable feedback practices, with self-regulation at its core (Carless, Salter, Yang & Lam, 2011, p. 396). Nicol (2010) supports this claim by writing 'While the quality of the comments is important, the quality of the students' interaction with those comments is equally, and perhaps more, important' (p. 503). Carless (2006), in his comprehensive analysis of written feedback on assignments in a Hong Kong context, highlights another claim that that teachers often believe they give more useful feedback than students feel they receive (p. 225).

New perspectives on feedback practice in addition to structural reforms in higher education together give ample reasons for conducting more research on feedback (Carless et al., 2011; Evans, 2013). Among the many areas of research on feedback, McGrath, Taylor, and Pychyl (2011) point out, it is '…of the utmost importance to determine the type of feedback students find most beneficial' (p. 1), and students are in a good position to determine if the feedback is beneficial as they are the recipients of the feedback (Price, Handley, Millar & O'Donovan, 2010). However, students may not always remember or able to articulate the type of feedback they have received. Although a growing body of research explores students' perceptions of written feedback in coursework, few studies consider oral, face-to-face feedback in the context of supervised capstone projects. The objective of this study is to critically examine how students perceive the feedback received in their projects. The aim of this study is to enrich our knowledge of how bachelor students utilize their oral feedback. This study was designed to answer the following research questions:

1. What types of oral feedback comments from supervisors do bachelor students find most useful when completing their final capstone projects?
2. What conditions must be met, according to the students, for them to benefit from this feedback?

In the following, I will present the analytical framework and research design used to investigate these questions, followed by the results, a discussion of these results, and a conclusion which I believe contribute to identifying and systematising factors that will improve the students' feedback utilisation in their learning processes.

Analytical framework and Research Design

To be able to answer the research questions, open-ended in-depth interview data were collected and then analysed using the *PLUS model* (Karlsen, 2015). This model is multidimensional, flexible and distinguishes four aspects of feedback—form, focus, purpose and temporality. Each aspect is defined by 2–8 categories or codes (see Figure 1). The connections between the aspects are decided by how the aspects and codes are combined. The combination form a 'pattern of feedback', expressed as 'form/focus/purpose/temporality'. The model allows for 192 different combinations (8 x 4 x 3 x 2). The following summarises the PLUS model. However, for a full description, see Karlsen (2015).

The first aspect, the form of the feedback, captures different ways teachers formulate and deliver feedback to students. The model describes eight forms of feedback: correction, explanation, judgement, suggestion, emotionally charged response, brainstorm, question and interpretation. The second aspect, *the focus of the feedback*, concerns what the feedback addresses, for example, a method or strategy students employ, the argumentation of an essay or the students' capacity for self-regulation. Similar to de Kleijn, Mainhard, Meijer, Brekelmans, and Pilots (2013) and Jolly and Boud (2013), the PLUS model uses Hattie and Timperley's (2007, p. 86) four levels at which feedback operates to define the focus of the feedback: product, process, self-regulation and person. The third aspect, the purpose of the feedback, categorises what teachers want students to learn, for example, to help the students see the beauty in a painting, to be able to follow a code of professional conduct or to become more motivated. The model uses established classifications of educational objectives to define the purpose of feedback as consisting of the cognitive, affective and psychomotor domains (Bloom, 1956; Krathwohl, 2002; Krathwohl, Bloom, & Masia, 1964; Simpson, 1966). The fourth aspect, the temporality of the feedback, describes the temporal direction of feedback vis-à-vis its focus. Feedback is commonly distinguished as either 'feed-back' or 'feed-forward' (see, e.g. Nicol, 2010; Sadler, 2010; Walker, 2013). These are the terms used for the temporality of feedback in the PLUS model.

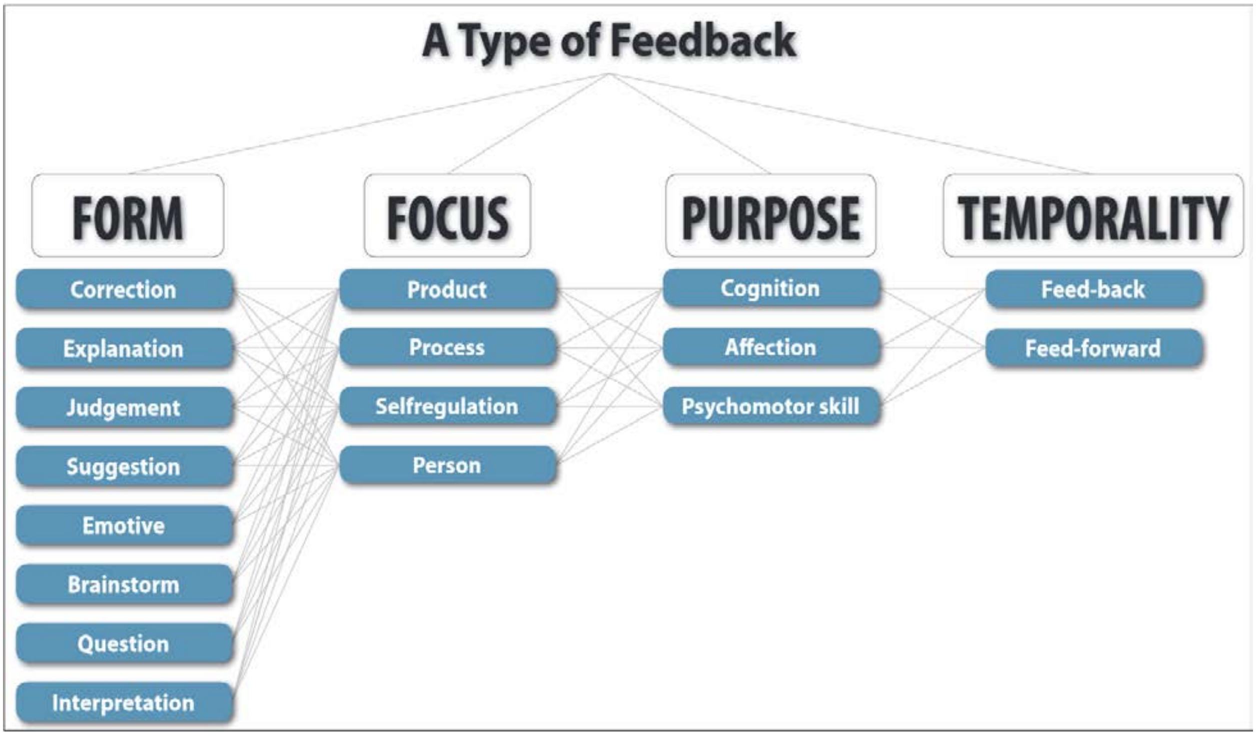

Figure 1: The feedback classification scheme used in coding

As mentioned earlier, the PULS model was used analysing the data gathered in this research. The data comprises of face-to-face interviews of 28 bachelor's students; twenty taking the bachelor's degree project course as part of an industrial design programme, and eight taking a design course as part of a computer science programme. In both bachelor programs during their sixth semester, the students must complete a capstone project that ends with an exhibition of the projects, an EXPO. The aim of the courses is to develop the students' competence and self-esteem in carrying out real projects. Throughout the course, they practice working in teams systematically, according to recognized methods and models for project management, problem solving, development and evaluation. During these courses, students from both programs work in groups of 3-4 to design and make prototypes to solve genuine work-based challenges as defined in cooperation with the academic supervisor and an external company (see last column table 1). The 28 students worked nine different bachelor projects summarised in table 1. The first column gives an overview of the end products each of the groups designed. The second column divides the projects in two cohorts based on whether the cohort is an industrial design (group 1-7) or an interaction design (group 8-9).

TABLE 1: CAPSTONE PROJECTS

Gr.	END PRODUCT	TYPE OF PROJECT	EXTERNAL COMPANY
1	A prototype of a veterinary examination table	Industrial design	Norwegian University of Life Sciences
2	A prototype for mobile navigation- and communication device for infantry soldiers	Industrial design	Norwegian Defence Research Establishment (FFI)
3	A car entering the Shell Eco Marathon race	Industrial design	Shell Eco Marathon / Shell Global
4	A prototype of a control surface with large displays to monitor nuclear reactors	Industrial design	Institute of Energy Technology (IFE)
5	A prototype of a control surface with large displays to monitor nuclear reactors[2]	Industrial design	Institute of Energy Technology (IFE)
6	Working prototype of an environmentally friendly lamp	Industrial design	Noral Green Light
7	An evaluation of a self-driving robot vehicle	Industrial design	The University College
8	A Public displays design for giving concise information to employees, students, and visitors at the college.	Interaction design	The University College
9	A working prototype of a mobile application designed to give access to a library catalogue based on location.	Interaction design	Norwegian federal library, Deichmanske

An example of an industrial design project made for the Norwegian University of Life Sciences is the prototype of a veterinarian examination table on which dogs could be transported. The prototype focused on the transition from the use of finished profiles using steel to finished profiles using aluminium. Another industrial design example is the car designed for the Shell Eco Marathon race, a race challenging students around the world to design, build, test and drive ultra-energy-efficient vehicles (see Shell Global, 2017). As an interaction design project, the students were challenged to create a new public display design for giving information via flat screens to students, employees and visitors at the university college. This project focused layout design in addition to extension of relevant support features such as video performance, interaction and impact for users. Figures 2-4 illustrate students working on their projects and examples of their prototypes.

[2] Group four and five, both worked on designing the same prototype.

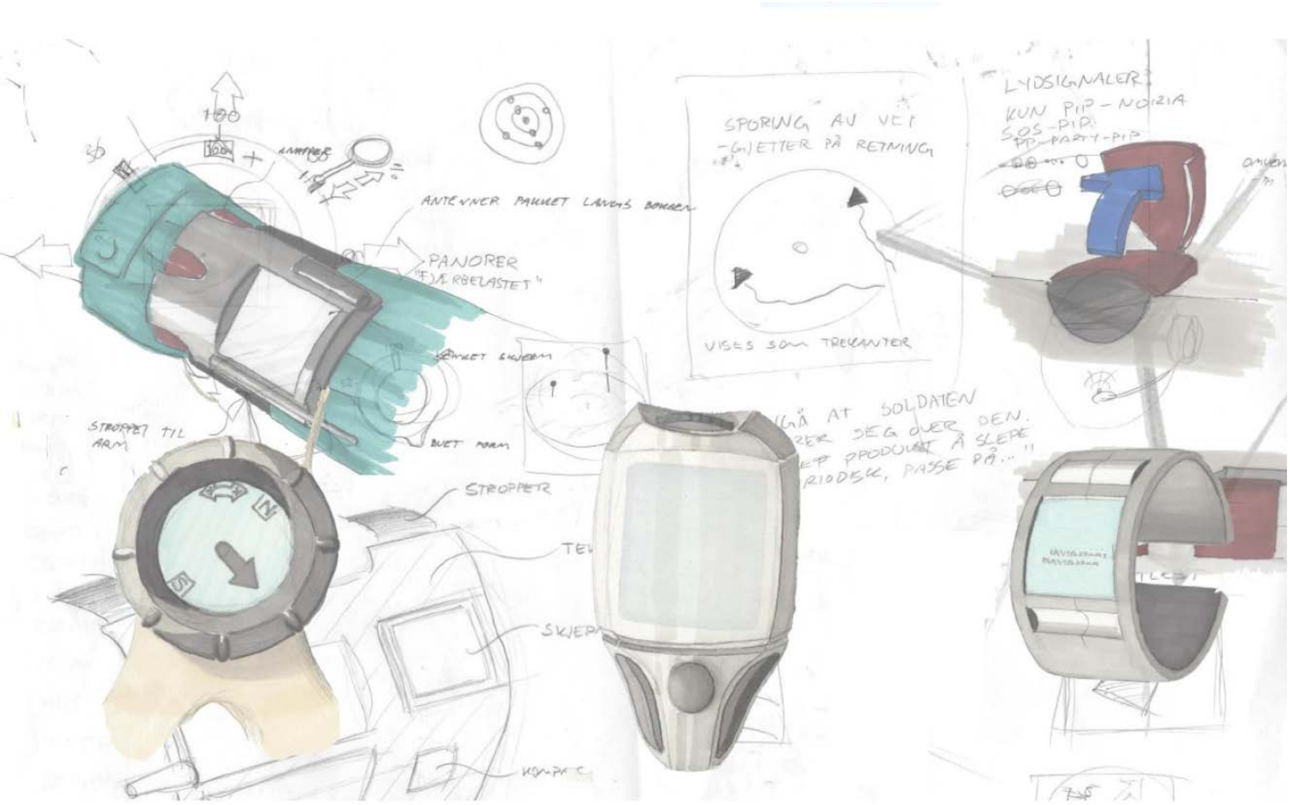

Figure 2: Students developing different concepts design.

In the capstone projects, the students attended discussions with their supervisor on an average of once a week. Little or no other teaching was provided outside of these critiques, a type of practice with long-standing tradition in design fields (Chamorro-Koc, Scott, Coombs, 2015; Dannels & Martin, 2008). These critiques concerned various aspects of the students’ work, changed in its style throughout the different phases of the project. Feedback could, for example, begin with getting the students started, ensuring that the project idea was related to their field of study, guiding the analysis, prototyping and testing, and giving feedback that ensured the students adhered to what they said they would do. Later, an example of feedback could include supervising the final report and preparation for the EXPO. At the EXPO, the supervisors were particularly concerned that the students could discuss and evaluate their designs. The supervisors were concerned that the feedback they gave should be as objective as possible and somewhat independent of their own preferences, or as one stated, 'Although I have my own taste or what I think is nice or working, you as a supervisor must try to give feedback relatively objectively. I as a teacher do not own the truth'. The feedback was given with the belief that the students themselves had main responsibility for their work and progress, and that the supervisors’ role or desire was to create a learning environment that encouraged students to discuss reasons for the choices they had taken, as one supervisor explained,

I ask the students why they have shaped the [product] as they have done, and this makes them take a standpoint on their decisions. It's not enough to say that it's pretty […] The style of such supervisions is completely conscious, and I have learned this from my own supervisors.

One of the industrial design supervisors was keen to convey that in this course, they 'teach design crafts, not design theory, which means discussions and feedback is on a practical level. Of course, the students’ understanding of conceptual theory is also part of the feedback'. Each main project received an individual grade, A-E. For the most part, each student received the same project grade, as long as there was no differentiation of responsibilities and contributions that suggested that the grade should be given individually.

Figure 3: Student working on the design to generate different concepts.

The interviews occurred at the end of the course at the educational institutions in question, creating a sense of security and proximity to the topic of conversation. Having spent 14 weeks in these environments before conducting student interviews, I acquired sufficient knowledge of the practices used in the different programmes, the professional language used by the supervisors and supervisee, the assignment given to the students and the feedback types used in the dialogues between the participants (see Karlsen & Karlsen, 2012). This knowledge was used to develop an interview guide using a language the informants could relate to and understand. The individual semi-structured interviews were conducted to allow each individual student time and space to express his/her own viewpoints, reflections and opinions. To encourage this, I took a sensitive, open approach using confirmation and encouragement. However, in order to verify interpretations and improve the interview response reliability, I also used a guiding, clarifying approach, requiring precise, critical questions and interruptions (Kvale & Brinkmann, 2015). The interviews lasted approximately one hour. All were recorded and transcribed before being analysed.

Figure 4: Student developing a working prototype.

In coding, data TAMS Analyzer software (Weinstein, 2006) was used. This software enables efficient coding, storage and reporting of coded information. To investigate the first research question of the types of feedback students found useful, two initial categories were used: useful and useless. This dichotomy is an over-simplification that will miss much information about degrees of usefulness, but it gave an impression of which feedback patterns students found either useful or useless. The following excerpt illustrates a situation where feedback was perceived as useful:

… we were about to start on the bachelor's degree project. We were going to make a design for a car, and we had one of those quick sessions with the supervisor where *we sat and just had a total brainstorm*. The supervisor brought up experience that he had gained from the previous projects about things we should do and things we should not do under any circumstances, and then we started to think. What I mean is, we immediately started to work and design on that basis, thinking "OK, we must avoid that" …and we arrived at the design a bit later, based on his idea that "Yes, I wish for you to manage something creative and very asymmetrical". It was an idea that he had and that we considered and decided to proceed with.

After classifying the feedback as either useful or useless, the PLUS model was used to further categorize and code the types of feedback. For example, we sat and just had a total brainstorm… was coded as 'brainstorm'. In addition, the feedback was coded as 'product', relating to the design of a car that they would create in the future, coded as 'feed-forward'. According to this student, the supervisor also wanted to promote their understanding of how the product may look, coded as 'cognition'. This feedback was given the pattern 'brainstorm/product/cognition/feed-forward', which is in this case registered as 'useful'. In some cases, students' descriptions were insufficiently detailed for the PLUS model to be used in full. Therefore, the analysis quality depended on good follow-up questions that could stimulate elaboration of the students' answers. Generally, short statements were easiest to code because they usually were coded with only one feedback pattern. Ambiguous statements were often most difficult to code, and in some cases a statement was given double codes. Druckman (2005, p. 263) states that coding is based on an interpretation process undertaken according to categories designed to identify elements as they occur in a text. Even though there are no right or wrong coding decisions, some are more plausible than others.

In addition to plausibility, it is important to note that this study is based on a small sample size, 28 design students at one university college, and based on self-reported descriptions of oral feedback received during their bachelor projects. Caution must be applied, as the findings cannot be generalised to the supervision of students at other institutions, in other subjects or at other levels of study. Still, the results confirm some of what is already known from previous studies, which may indicate possible common challenges across feedback situations, academic communities and traditions.

A final methodological point must also be noted. Had the interviews been conducted immediately after feedback was given and not at the end of the course, the results might have differed, as students' perceptions could change over time. Feedback they did not immediately consider useful might nevertheless be considered useful later in the process. However, the opposite could also be the case. Students could forget overtime what feedback they received, particularly feedback that was not immediately deemed useful. In fact, students could actually be wrong about what was useful to them. What students think is useful is one thing; what is actually useful feedback is another. Jolly and Boud (2013) support this claim when stating, 'What students say they want might not be the same as what they need' (116). Having described the analytic procedures and methods used in this study, the next section is divided into two main parts, each section presenting the results related to one of the research questions.

Results

The occurrence of useful/useless Feedback Patterns

Fifty-three feedback patterns were identified using the PLUS model to code feedback comments. This means 53 of the model's 192 possible patterns were found. Table 2 summarises the patterns most frequently described as useful or useless. To present the results systematically, the patterns are grouped by similarities when combining the model's three last aspects, focus, purpose and temporality (Table 2). Ten groups (column 1) express 34 feedback patterns which represent those patterns that are mentioned by two or more students. The columns labelled 'useful' and 'useless' describe the number of students who found the feedback either useful or useless.

The most commonly occurring feedback patterns are in the groups 1–4 (column 1). In three of these groups, the most frequent patterns are coded as both *useful* and useless. All patterns in the four groups include cognition, meaning that the feedback is intended to strengthen students' intellectual abilities. The most common feedback forms are corrections (patterns 2, 7 and 13), explanations (patterns 3 and 8), judgments (patterns 1 and 12) and suggestions (patterns 6 and 14). Feedback focusing on products found in groups 1 and 2 is coded more frequently than feedback focusing on the students' learning process, groups 3–4. Feed-forward patterns are coded slightly more often than feed-back patterns. Of the 192 possible patterns, 139 were not found in data. This is primarily because no statements were coded with 'psychomotor skills', which account for 64 patterns. In addition, only five of the 48 patterns that include self-regulation were identified.

Interestingly, there is conclusive evidence that the feedback in this study is coded more useful than useless. Even though feedback patterns coded as 'product/cognition' found in groups 1–2 occur more frequently as useful than feedback coded as 'process/cognition' found in groups 3–4, the number of patterns tagged as

TABLE 2: OCCURRENCE OF USEFUL/USELESS PATTERNS

Group	No.	FORM	FOCUS	PURPOSE	TEMPORALITY	USEFUL	USELESS
						No. of students	No. of students
1	1	Judgment	Product	Cognition	Feed-back	21	16
	2	Correction	Product	Cognition	Feed-back	16	7
	3	Explanation	Product	Cognition	Feed-back	13	1
	4	Emotives	Product	Cognition	Feed-back	9	4
	5	Questions	Product	Cognition	Feed-back	2	4
2	6	Suggestion	Product	Cognition	Feed-forward	20	10
	7	Correction	Product	Cognition	Feed-forward	18	12
	8	Explanation	Product	Cognition	Feed-forward	17	6
	9	Questions	Product	Cognition	Feed-forward	6	1
	10	Emotives	Product	Cognition	Feed-forward	5	2
	11	Brainstorm	Product	Cognition	Feed-forward	4	–
	12	Judgment	Product	Cognition	Feed-forward	2	1
3	13	Correction	Process	Cognition	Feed-forward	19	9
	14	Suggestion	Process	Cognition	Feed-forward	16	4
	15	Explanation	Process	Cognition	Feed-forward	8	3
	16	Judgment	Process	Cognition	Feed-forward	4	1
4	17	Judgment	Process	Cognition	Feed-back	11	1
	18	Correction	Process	Cognition	Feed-back	2	–
	19	Emotives	Process	Cognition	Feed-back	2	–
5	20	Emotives	Person	Affection	Feed-forward	7	–
	21	Correction	Person	Affection	Feed-forward	5	1
	22	Judgment	Person	Affection	Feed-forward	3	–
	23	Explanation	Person	Affection	Feed-forward	2	–
	24	Questions	Person	Affection	Feed-forward	2	–
6	25	Emotives	Person	Affection	Feed-back	5	3
	26	Judgment	Person	Affection	Feed-back	3	2
	27	Correction	Person	Affection	Feed-back	2	1
7	28	Correction	Person	Cognition	Feed-forward	3	–
	29	Explanation	Person	Cognition	Feed-forward	2	–
8	30	Judgment	Person	Cognition	Feed-back	–	2
	31	Correction	Person	Cognition	Feed-back	–	2
9	32	Questions	SRL	Cognition	Feed-forward	2	–
	33	Correction	SRL	Cognition	Feed-forward	2	–
10	34	Emotives	Process	Affection	Feed-forward	2	–

the number of patterns identified is higher in groups 3-4, with a ratio of 3:1, than in groups1-2, with a ratio of 2:1. In other words, patterns in groups 3-4 are coded three times more often as useful while the patterns in groups 1-2 are coded only twice as often as useful. In addition, a higher percentage of patterns coded as 'feed-forward' are tagged as useful in comparison to patterns coded as 'feed-back'. Correspondingly, future-oriented patterns are coded as useless slightly more often than patterns coded as 'feed-back' which is a result of the total number of coded patterns being higher in patterns coded as 'feed-forward'. Judgments and corrections are the two feedback patterns most frequently coded as both useful and useless, while explanations and suggestions more often coded as only useful (see, e.g. patterns 3, 6 and 8).

The above demonstrates the coding necessary to address the first research question of this study. The second research question can be addressed by framing in greater detail the conditions students deemed necessary for them to benefit from feedback. The following section is organized into three parts: the context in which the feedback pattern emerges, the students' confidence in the supervisor, and the students' own investment in the feedback dialogue.

Conditions for Feedback Patterns to be perceived as useful

The feedback pattern found in group one, coded as 'judgment/product/cognition/feedback' is the pattern used to help identify the conditions presented in the following three parts. This feedback pattern was chosen because it was the most frequently coded pattern in all the interviews.

The sequence in which the Feedback Pattern emerges

The first condition necessary for students to consider feedback as useful depends on the sequence of which the pattern occurs and is independent of whether the comment is positive or negative ('this is good' or 'this is bad'). In other words, the context in which the pattern appears is important in determining how students perceive the feedback given by their supervisors. 'Totally disregarding the work done, with no constructive suggestions, is the worst type of feedback you can possibly get' is an example of a pattern coded as 'judgment/product/cognition/feedback' and considered useless. However, the following illustrates the same coded pattern as useful:

	STUDENT STATEMENT	CODING
1:	So it wasn't just like, "Yes, great! Go ahead!"	
2:	It was first, like, "Okay, why is that?" and "Why does it look like that?"	[Question]
3:	And then, I had to explain that, well, it is aerodynamic and it has a tear-drop	
4:	shape. And when we had to say, "Yes, we want to build it like this, and we	
5:	have bigger and simpler surfaces than before so that we can do it ourselves"	
6:	and then you can tell that they became more and more reassured that "wow,	[Judgment]
7:	they thought this through", and then they sort of follow up by saying that	
8:	"yes, that, I think this is good", or, if something isn't good, [then they will	
9:	say that]; usually it's a bit of both, of course.	
10:	And then they usually say that "you should think through and reconsider	[Correction]
11:	that and maybe choose a different solution there" and things like that.	[Suggestion]
12:	And I think that is a very good thing, that they give both criticism and	
13:	encouragement, that is, in such supervision sessions.	

The above example illustrates a specific sequence of four patterns. The sequence of these patterns seems to affect the students' evaluation of the judgment given by the supervisor as relevant and meaningful. The judgment described (lines 8–9) was not delivered in isolation but came after two questions (lines 2), followed by a correction (line 10) and a possible suggestion (line 11). In the first example where the judgment was considered useless, the judgement occurred in isolation, 'with no constructive suggestions'. The absence of other patterns of feedback appears to be a reason the comment was considered as 'the worst type of feedback you can possibly get'. In a third example, one student explains why it is insufficient for a supervisor to just say 'fine', 'good' or 'not so good' by saying that 'you don't really learn anything, because you don't know what you did well or what you did badly so that you can do better next time'. The data clearly supports that the usefulness of the feedback pattern coded as 'judgment/product/cognition/feedback' is more dependent on the sequences of patterns than on the individual patterns themselves. Although the above examples use only the feedback pattern 'judgment/product/cognition/feedback', analysis indicate similar results for other feedback patterns as well.

Confidence in the Supervisor

In addition to the sequence in which the feedback pattern emerges, the usefulness of feedback was also related to students' perception of the supervisors' personal characteristics. The following is an example of a student describing a supervisor as having high credentials:

He is a highly merited designer, working in the field that we may also eventually work in… I think that I will remember him as a good supervisor after many years – that sounded almost like he's passed away – and as a person who had a lot to contribute and who, if you were in the middle of a situation as a designer, you might consider calling, simply for feedback. He would probably have appreciated that. So yes, I believe he has left his mark on most of us, including me.

Based on data, two specific elements working together contribute to the perception of a supervisor. Is the supervisor sufficiently competent? This relates to his/her perceived knowledge, experience and qualifications and his/her reputation and position. The other element is whether the supervisor takes his/her duties seriously. Do the students feel that the supervisor takes the time to familiarise himself/herself properly with the projects on which feedback is provided, and does the supervisor invest time, interest, care in the relationship with the students. Below, describes an episode where a positive judgment (line 5) on a midway report was perceived as less good or useless feedback (line 7). These statements describe product-focused feedback delivered in the form of judgments, coded 'judgment/product/cognition/feed-back' (i.e. pattern 1, table 2).

LINE	STUDENT STATEMENT	CODING
1:	We have talked a bit about how we have the impression that the supervisor may not	[Not sufficiently
2:	have read what we submitted, that he maybe just skimmed through it. It is just a	thorough]
3:	feeling, really, because we don't get any specific feedback [...]. It has just been sort	
4:	of superficial. But we don't know. It may have been thoroughly read […].	
5:	We got things like, "This was a good paragraph" and "There was an error here" […].	[Judgment]
6:	It makes it more difficult to correct things, then, if it is sort of "okay", but maybe it	
7:	isn't, really. So that makes it a bit more difficult afterwards perhaps […].	
8:	It's not certain that it's his fault, in a way. It may be that we should have submitted	[Own efforts]
9:	things more often […]. The supervisor said that we can just e-mail him stuff, but the	[Not sufficiently
10:	times we have sent him things by e-mail, he has replied, like, a week later and things	thorough/
11:	like that.	interested]
12:	[*Interviewer: But you say that you only get "this is good". Do you feel that you can trust the feedback you receive? Do you trust what he says?*]	
13:	I have confidence in his knowledge and all that, so if I were convinced that he used	[Sufficiently
14:	all his experience and knowledge to actually go through everything we write—or	competent]
15:	maybe not everything , but anyway—then one might have more confidence in it ...	
16:	There is no doubt that he has a lot of knowledge. It's just that he may not be putting	[Not sufficiently
17:	it to sufficient use regarding the work we submit […].	thorough]
18:	He may be taking it a bit lightly. There has been a bit of groaning and huffing, a bit	[Not sufficiently
19:	of body language, that suggests that it is an extra burden to be a supervisor, that it is	thorough/interested]
20:	something he would maybe prefer not to have to do.	

In this example, the student considers the supervisor sufficiently competent, a person who can be trusted because of his knowledge and experience (line 13–14). However, because the student suspects the supervisor does not take his duties seriously enough (lines 1–3, 16–18) and because he demonstrates a clear lack of interest (lines 9–10, 18–20); the judgment is not perceived as trustworthy. In a similar statement, another student dismisses much of what the supervisor says because she does not believe he has sufficient expertise (is 'sufficiently competent') on the topic. She always checks what he claims and that it has often proven to be wrong. She states the following: 'I guess that if you experience a person over a period of time, you get a certain impression of what [the person] is like. That either builds trust or diminishes it. In this case, I have lost it'.

Students' investment in the Feedback Process

The final condition necessary to consider feedback as useful depends on the students' own investment in the feedback process. There are two particular elements that reoccur in the analysis: the student's effort in the process and his/her attitude. These two elements are illustrated by the following statement: 'I think that we are getting a lot of good feedback, that we are also aware of, really, and that you want to make use of…soon, but then, I think that we are just too lazy, or just have the wrong attitude'. The first element, effort, relates to the following factors, whether the students had prepared well for the supervision in advance (submitted a document to the supervisor, made an outline, created questions or determined who is to say what) and whether the members of the group actually attend the session, fit and rested. One student said:

We have a certain responsibility ourselves, too, not just to have produced something but to have maybe thought about what we want from the supervision session and maybe also to have prepared more of an agenda for the meeting…It is we who are there to be helped, so then we have to find out what we need help with.

Another student admitted they could probably be more active and persistent in dealing with the supervisor, if they felt they were not benefitting sufficiently from the feedback: 'Pretend that this is a school like Harvard or something, where you pay a lot of money and expect to get ... well, your money's worth, to put it simply. That is how you should think, really'.

The second element, attitude towards the feedback process, is linked to student's expectations of feedback and to the extent of which the student trusts that the feedback won't be used against him/her. One student said, 'There have been days when my attitude has not been altogether positive, of course, and then I don't always want feedback. I don't know, but you have to try to keep a positive attitude, generally speaking'. Does the student dare to be open with the supervisor, not only about the strengths of the project but also its weaknesses? One third of those who were interviewed expressed concern that something stupid said during supervision would definitely affect their final grades. The following example displays how two students had very different approaches to supervision:

> *I am happy to display [weaknesses], while my fellow student is quite the opposite, or that is my impression at least. He wants to prepare for supervision, and then he wants to present the project as positive as possible. He does not want to draw attention to what is bad, and if our supervisor comments on something that isn't particularly good, he defends it fiercely. We are very different because I think that what we say in supervision won't affect our grade. I'm the opposite. I am happy to draw attention to things that I'm uncertain about…I trust my supervisor that much. However, although I probably didn't trust the supervisor [we had in our first year], I still drew attention to things I was uncertain about then, too.*

The interview conducted with the 'fellow' student confirmed the differences. The 'fellow' student said, 'You don't want to show weakness. You want to reinforce the positive things to make the best possible impression…eh…because then the supervisor will have a good impression of you. It will have a more or less direct effect on the grade, right?' Even though the student's attitude has no direct connection with a single feedback pattern, it may be relevant to a particular session or to supervision in general.

Based on the data, the two elements in the students' investment of the feedback process appear to have differing degrees of stability. The students' attitude appear more stable over time while the effort the students invest in the process may fluctuate throughout the process.

Discussion

Although McGrath et al. (2011, p. 1), suggest there exists a certain feedback type all students will find useful, a type therefore important for researchers to identify, the results of this research provide evidence that determining usefulness of feedback is more complex. This study demonstrates how one type of feedback can be perceived as both useful and less useful based on a variety of contextual elements, including the sequence of the feedback pattern, students' confidence in their supervisors and the students' investment in the feedback process. The following section explores these results further.

Useful feedback Patterns in the PLUS model

The PLUS model can only describe what type of feedback is given expressed as patterns (Karlsen, 2015), but classifications can be used more normatively to identify and reflect upon feedback practices (Brown & Glover, 2006). I will use the identified feedback patterns in the PLUS model to discuss theories and research found on feedback in higher education, theories and research that have previously focused on the occurrence of one aspect at time. Alternative to most reviewed studies on feedback in higher education, the PLUS model supports a richer description of feedback patterns as combinations of form, focus, purpose and temporality. However, due to lack of literature focusing on patterns of feedback, the following will discuss one aspect at a time.

The first aspect is the feedback form. In this study, feedback focusing on explanation was more frequently tagged as 'useful' and was rarely coded as 'useless'. Students appeared to appreciate explanations, which is supported by other previous research (e.g. Bailey, 2009; de Kleijn et al., 2013; McGrath et al., 2011). According to Brown and Glover (2006), referring to Sadler (1989,1998), explanations create a connection between the feedback and the students’ work, closing the gap between the current level of achievement and the desired level of achievement which is the core activity in formative assessment (p. 85). Similarity in research findings along with supporting theory suggest that feedback focusing on explanation is a valued component in effective feedback. Theory on feedback in higher education regards feedback in the form of judgement as useful in students’ learning process (e.g. Boud & Molloy, 2013; Molloy et al., 2013; Sadler, 2010; Walker, 2013). Students from this study supported these findings as they also relatively often assessed this form of feedback as useful. The low level of occurrences of the feedback forms 'brainstorming' and 'interpretation' in this study is another area that is supported by results of previous studies that also reported few accounts of these feedback forms. However, although these feedback forms were rarely identified, students considered both the forms as helpful when they were first mentioned, a result that is confirmed by previous research (see e.g. Kumar & Stracke, 2007 discussion of 'interpretation').

The second aspect is focus on feedback. Similar to other studies, the students in this study frequently report receiving product-focused feedback assessed as useful (Hyland, 2001; Kumar & Stracke, 2007). Along with other research based on various levels of education, the present study seldom reports the value of feedback focusing on self-regulation as useful (de Kleijn et.al., 2013; Harris, Brown, & Hartnett, 2015). In the current study, only five (of 48 possible) patterns that include feedback focusing on self-regulation are coded, and these five patterns are mentioned only by 2 or less students each, which is a contrast to product-focused feedback that are coded in 22 of the 28 interviews. However, in return the five patterns that focus on self-regulation are all coded as useful. That only a few consider self-regulation as useful is surprising, as the importance of self-regulation is well documented in theory (Butler & Winne, 1995) and self-regulation is described as the core activity in sustainable feedback (e.g. Carless et.al., 2011; Price, Handley, O’Donovan, Rust, & Millar, 2013). Hattie and Timperley (2007) report feedback focusing on product (and person) is the least effective feedback, unless the feedback is directly attributable to self-regulation (p. 90). The results of this current study, therefore, contradict the accepted theories of effective feedback, theories that point to self-regulation as more effective than product focused feedback. Possible explanations for this rather contradictory result may be that students do not assess, characterise or conceive self-regulation in the received feedback, or perhaps lack the words to describe self-regulation. These findings indicate a need to better define the concept of self-regulation in its use in theory and research.

The third aspect is purpose. Students frequently considered feedback intended to strengthen their intellectual abilities (prompting reflection and cognition) as useful. Likewise, Lephalala and Pienaar (2008), in their impressive analysis of written feedback on essays, found feedback focusing on critical thinking and reasoning to be the most effective feedback, although this feedback was rarely given to the students. Previous studies report similar results (see, e.g. Brown & Glover, 2006; Ivanič, Clark, & Rimmershaw, 2000; Orsmond & Merry, 2011). In theory on feedback, development of students' cognitive skills is found important to sustainable feedback but not more important than developing affective and psychometric abilities (Molloy, Borrell-Carrió, & Epstein, 2013; Nicol & Macfarlane-Dick, 2006; Yang & Carless, 2013). Students in the current study similarly placed value on feedback encouraging affective skills, reporting a high incidence of two important efficient domains (cognition and affection). Lacking in the current study are reports on feedback coded as psychomotor. Physical (bodily-kinaesthetic) learning is central for professions like design (Schön, 1987), and as the sample comprised students designing and producing products like veterinary table for dogs, it would be expected to find such feedback in the results. Psychomotor feedback may not necessarily be expressed in words but through nonverbal communication (e.g. supervisor showing a specific grip to use a tool) which is an aspect not included in PLUS model, which may also explain the results. This stresses the potential challenges of capturing physicality or “embodiment” (cf. Merleau-Ponty, 1994) in research. The role language plays in bodily learning is an interesting topic for futures studies.

The last aspect is temporality of feedback. Future-oriented feedback was often mentioned as useful in this current study, confirming what is already known about the effect of feed-forward (see, e.g. Brown & Glover, 2006; Donovan, 2014; Hounsell, McCune, Hounsell, & Litjens, 2008; Price et al., 2010; Walker, 2013; Weaver, 2006). Walker (2013), in her excellent investigation of students' responses to different types of written feedback, explains that feedforward better enhances student-tutor dialogue, as feedforward provides improved 'opportunities for students to adjust their future performance in response to comments received [and] therefore come closer to what Hounsell (2007) calls "sustainable feedback"' (Walker, 2013, p. 108). As mentioned earlier when discussing the first aspect, this last aspect supported by the combination of similar research and theory, confirms that feedforward is an important component in students' learning process.

In this study, students reported benefitting from the categories explanation, product, cognition, and feed-forward. All four of these categories are supported by research as useful feedback. Three of the four categories are supported by both research and theory as beneficial. Hypothetically, this could indicate the feedback pattern 'explanation/product/cognition/ feed-forward' is useful feedback for this kind of supervision. Nonetheless, as we know from Table 2 (line 8), this pattern is not always perceived as useful, indicating that usefulness depends also on the sequence of which the pattern occurs, varying confidence in the supervisor, and students' investments in the feedback process. The following further discusses the complexity of these contextual conditions as reported in this study.

The sequence of Patterns, trust in the Supervisor and Students' investment

The first contextual condition indicates that the sequence in which a statement is made foresees the degree of utility more than the singular pattern itself, a claim also supported by Kjeldsen (2006):

> *...it is not enough to praise and criticise. You must always give specific examples of what you praise or criticise, and say how it is good or bad […] to exemplify how something could be done differently and say why that would be better (p. 166–167).*

Students in higher education seem to want precise, detailed feedback that allows them to improve their work (see, e.g. Carless, 2006; Ferguson, 2011; Lizzio & Wilson, 2008; McGrath et al., 2011). That said, few studies in higher education focus on the importance of the sequences for students' perceptions of benefit. An exception is the well-known effect of squeezing negative criticism between two positive comments (cf. Gardner, 2004; Hyland & Hyland, 2001; Kjeldsen, 2006), known as the feedback sandwich (Docheff, 1990; Molloy, 2010; Molloy et al., 2013) or the sugar-coated pill method (Dunworth & Sanchez, 2016). Mapping sequences can give a deeper understanding of how certain types of feedback may be more or less useful depending on what comes first and what comes after in one dialogue. More studies are needed to expand our understanding of how sequences of patterns relate to students' perceptions of the feedback given.

The next contextual condition that is of equal importance for perceived utility depends on how much students trust the person delivering feedback. This confirms what is otherwise known about the importance of the supervisors' characters and how they present themselves (e.g. Chabaya, Chiome, & Chabaya, 2009; de Kleijn, Meijer, Pilot, & Brekelmans, 2014; Dysthe, Samara, & Westrheim, 2006; Kumar & Stracke, 2007; Lizzio & Wilson, 2008; Pitts, 2005; Poulos & Mahony, 2008; Price et al., 2010). Poulos and Mahony (2008) in their in-depth study of undergraduate students' perceptions of feedback, find 'the usefulness of feedback provided and hence its credibility was related to the students' perceptions of the lecturers themselves (p. 145). Pitts' (2005) small-scale study discusses bachelor's students' willingness to take responsibility for improving practice, and she links trust to assessments of how thorough a supervisor's work is—that the supervisor invests time and energy in familiarising him/herself with the students' work. Students see 'a scribbled comment' and 'hasty judgement' as an 'indication of lack of care and interest in their work, which lessens their trust in the tutor's professional judgement as well as potentially threatening their own self-confidence through carelessly negative comments (Pitts 2005, p. 221). Chabaya et al. (2009) use the expression gulf of mistrust (p. 219) to describe the mistrustful relationship between supervisor and supervisee identified in their mixed-method case study at Zimbabwe Open University. Dysthe et al. (2006) asked students what they believe is the most important success factors for feedback in supervision at the master's degree level at a Norwegian University. The students ranked trust, safety and sensitivity as most important. Dysthe et al. (2006) state 'This tells us that feedback has a very strong relational component that cannot be disregarded in any supervision context, particularly in groups' (p. 311).

The concept of ethos used in rhetoric reflects a speaker's credibility. According to Kjeldsen and Torhell (2008), ethos 'is important to making people listen, and quite crucial when it comes to convincing them, because we do not only consider what is said, but also by whom it is said' (p. 118). They argue that there are the three virtues used in ancient rhetoric—wisdom (competence), good character and goodwill—in relation to the recipients that enable us to 'appear convincing and credible even if certain dimensions of our ethos have been damaged' (p. 120). When a student in this study expressed 'I have confidence in his knowledge, so if I were convinced that he used all his experience and knowledge to actually go through everything we write […] then one might have more confidence in it'. This statement is an example where the supervisor's 'goodwill' has been damaged. Because of this, the student does not value the feedback, although the other two dimensions of the supervisor's ethos are considered strong.

The third and final contextual condition is the students' investment in the feedback. The importance of student effort and attitude towards the feedback process are also endorsed by the research findings of Mirzaee and Hasrati (2014), who argue that feedback by itself is ineffective and that students 'need to reflect on, respond to, and act upon feedback for learning to occur' (p. 562). Higgins, Hartley, and Skelton (2002) found as many as 39% of students spend less than five minutes on received comments, implying a lost learning opportunity, although other researchers (Donovan, 2014; Giles, Gilbert, & McNeill, 2013) suggest that most students do care about reading their feedback. This could be an indication that students' commitment to the role of a student varies. Rae and Cochrane (2008) separate students into two main categories based on their level of engagement. Some students make active use of feedback and are 'very keen to learn from it and develop academically. By contrast, other students seem to lack motivation and understanding, with a distinct lack of intent to learn' (p. 221).

Rae and Cochrane (2008) not only categorise students in terms of engagement, they also identify both teachers and students confusing formative purposes of feedback with summative which in turn effects the students' attitude towards feedback. This confusion between formative and summative purposes of feedback may be the basis of the mistrust mentioned earlier by the student reluctant to show weakness in his project during the feedback process. The notion 'that assessment and feedback is a transmission process centred on deriving and justifying a mark, rather than encouraging learning, seems to be predominate' (Rae & Cochrane, 2008, p. 221). Correspondingly, Li and De Luca's (2014) in their thorough review of 37 empirical studies notice 'tensions between formative and summative roles of assessment' (p. 390). Tease, Havnes and Lauvås (2005) state an important precondition for feedback to function optimally is that the system works as it should, officially as well as in reality (p. 65). As reported by Taasen et al. (2005, 65), it is naïve for students to 'believe in the "formative talk" when it eventually emerges that there was a summative element involved after all'. In this perspective, reluctance in revealing weakness may be a beneficial approach to feedback in the long term. In the current study, as many as one third of the students may have been 'cue seekers', playing what Miller and Parlett (1974) name 'the examination game' (p. 59). Snyder's (1971) excellent work on 'hidden curriculum' also highlights these opaque, informal aspects of higher education assessment practices, drawing attention to potential 'hidden curriculum' containing messages that suggest strategies for academic survival and success that students pick up and pass to other students. These language games can include conflicts between teachers and students and contribute to negotiations based on fear and mistrust rather than dialogues based on trust (Snyder, 1971, p. 186). Snyder (1971) put forward the argument that, 'Where there is fear of exposing oneself...negotiation is likely to be the mode' (p. 186). Therefore, the hidden curriculum can easily work against the formal goals of professors and students (Snyder, 1971, p. 13) and render feedback situations less effective. Without a doubt, hidden practices should be articulated and addressed in the research aiming to understand and improve feedback practices.

The above discussion has demonstrated how one type of feedback can be perceived as both useful and less useful. A variety of contextual elements, including the sequence of the feedback pattern, students' confidence in their supervisors and the students' investment in the feedback process must be met, according to these students, for them to benefit from feedback.

Conclusion

This study examines what feedback 28 bachelor's students doing their capstone projects report as useful. The study also explores factors on which they base their assessment of how useful the feedback is. Main findings are that students generally find supervisors' feedback more useful than useless and that the utility of this feedback varies qualitatively according to the sequence in which it occurs, supervisors' personal characteristics and perceived trustworthiness, and students' investment. That psychological aspects and students' efforts are important to their perceptions of feedback confirms previous findings, but the importance of the sequence in which a pattern occurs has not been extensively studied, and is an area for further research. In this study, students report less often feedback focusing on self-regulation, one of the most important elements in sustainable feedback practice (Carless et al., 2011). This result is also confirmed in de Kleijn et al.'s (2013) results. The lack of students' focus on self-regulation could be due to reasons other than supervisors not providing such feedback. Supervisors perhaps could raise students' awareness of the usefulness of self-regulation and endeavour to engage them in explicit dialogues about the usefulness of this feedback type. This study does not provide a basis for drawing conclusions about the relative importance of the sequence of which the pattern occurs, the personal characteristics of supervisors or students' own investments, and one can assume that several factors play a role and that the interaction between them is important. For example, the importance of good cooperation in the student group as a factor that influences the perception of feedback is one example not considered in this article, although this factor was mentioned in the interviews.

Based on this study, the key is to create good environments for feedback that take seriously situations in which students and teachers in higher education find themselves, situations that include time pressures and increased class sizes. These situations have contributed to the need to prioritize and understand what is beneficial supervision and feedback at this level. This article points out some of the conditions that may need to be met in order create these environments, however there is a need for more research-based knowledge that can contribute to further development of feedback practices in higher education, for example research addressing 'hidden practices' as discussed in this article. Another interesting path is to look into ways of providing feedback with the aim of psychomotor skills, an area especially relevant for practice-aesthetic subjects like design. A final example of a research area is the further exploration and development of supervisor and supervisee feedback literacy, enabling more 'meta reflection' on the feedback situation. This study demonstrates how the PLUS model can be used to identify and systematise factors that might help students improve feedback utilisation in their learning process, a model that can be used in the further research needed in this area.

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Creativity Assessment in the Context of Maker-based Projects

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Abstract

Creativity is a key competence in 21st century education. Among the active learning pedagogies which aims to develop creativity, learning by making is an emerging approach in which the students are engaged in the co-creation of a shared artefact. In this study, we aim to analyse the creativity competency through a maker-based projects. #SmartCityMaker project aims to design and to build a smart city model. We analyse the creativity competency through a rubric-based assessment and discuss the opportunities of creative project-based challenges in the development of creativity in maker-based projects in Higher Education.

Key words

creativity; higher education; maker; teaching practices; project based learning

Creative education

Creativity is a key competence for facing the social challenges of post-industrial knowledge societies (Garrison, 2011) and is increasingly considered as an important competence in relation to the current and future society (De Bono, 2015; Florida, 2014; Sternberg & Lubart, 1995). Creativity could be observed when participants engage in the design of a new, innovative and pertinent way to respond to a potentially problematic situation, which is valued by a group of references in a context-specific situation (Csikszentmihalyi, 1996; Franken & Bauers, 2002; Romero & Vallerand, 2016). Despite the importance of creativity and collaboration in 21st century society (Hesse, Care, Buder, Sassenberg, & Griffin, 2015) and the increasing differences between the "creative class" and the other citizens (Florida, 2014), creativity in educational settings is still not being considered as a key priority by some educational actors and is considered less important than disciplinary content (Willett, Robinson, & Marsh, 2012). While creativity is being included by policy makers (Shaheen & others, 2010) in K-12 curriculum, most teachers are often still focusing on knowledge acquisition (Boutonnet, 2015; Davies, 2004; Molin & Grubbström, 2013) rather than on competency development such as creativity. Creativity is also still not part of the daily academic discourse (Kleiman, 2008) in higher education (HE). One reason that could explain the scarcity of studies on creativity in HE is that creativity poses a challenge to the HE organisational system that often relies on compliance and constraint, but also the richness and complexity in the way academics and teachers perceive creativity (Kleiman, 2008) and design-based learning (Kimbell, Stables, & Sprake, 2002). Jahnke, Haertel and Wildt (2017) observe that there is no unique understanding of what creativity is and highlight HE professors' view of creativity as something that is subjective and as a process that is mostly individual. Despite the multifold aspect of creativity, they are features of creativity that are often mentioned by scholars when it comes to defining it, such originality, novelty and relevance. These different creativity traits are often considered in individual context, as a process and a product obtained by the creative process of a subject

(Sternberg & Lubart, 1995). In the literature, creativity has been mainly developed and analysed by individual activities (Romero, Hyvönen, & Barberà, 2012), which are often limited in their scope of supports to express learners' creativity. In this paper, we consider creativity as an individual or collaborative reflective iterative process (Runco, 2014) that aims to design a new, innovative and pertinent way to respond to a potentially problematic situation, which is valued by a group of references in a context-specific situation (Csikszentmihalyi, 1996; Franken & Bauers, 2002; Romero & Vallerand, 2016a). The creative process leads the learner to explore several new solutions to a problem, to use inspirational work in order to orient thinking and finally to select a solution while considering the context of the problematic situation. Therefore, creativity in educational contexts is defined by the balance residing between divergent, convergent and associative thinking. Exploring new and purposeful solution relies on students' ability to think divergently (Guilford, 1962), by generating original possible solutions and by thinking convergently in establishing congruencies between these new solutions. Thinking creatively and finding original ways to solve problems often relies on learners' competency to recognise the value of existing praised solutions in the same or in a different context that can inspire finding a new solution. Combining two different elements coming from different contexts is defined by associative thinking (Benedek, Könen, & Neubauer, 2012; Howard-Jones, 2002). Assessment of the new-found solutions is a process than can be led individually and collectively, but also by a member outside of the creative process possessing an authority (or credibility) in the domain. We also stress the importance of iteration in the creative process. After being assessed for the first time, it is important to allow time for learners to adjust components of the solutions that were not adapted to the context. We therefore argue that creativity in education echoes some key principles of design thinking. Creativity also depends on the convergence of several factors such as disciplinary competencies, process-relevant factors guiding the direction and progress of the creative process as well as social and environmental features that ensure a supportive environment that enables students to be confident, motivated and able to take risk (Rutland, 2009). As educational contexts do not always allow for creativity development to be the main learning goal, we also wish to stress the importance of the creative margin in the results and in the process. For example, educational context sometimes calls for every learner to produce the same result, yet by a different process while sometimes it is the process that is mandatory, but each result can be unique. This definition of the creative process triggered by a problematic situation echoes Vygotsky's double stimulation concept where learners collectively engage in overcoming critical conflicts by using mediating cultural artefacts in order to create a solution that emancipates them from this problematic situation (Vygotsky & Rieber, 1997) by feeling confident to take risks. Considering pre-existing literature on creativity in educational context, the scarcity of studies on creativity in HE as well as the pre-eminence of knowledge acquisition over competency development like creativity, we therefore wish to address these important issues by investigating how creativity can be developed in HE without jeopardising acquisition of content-related knowledge? This study is part of the #CocreaTIC Participatory Action Research (Whyte, 1991) project that aims to offer a better and practical understanding of 21st century competencies development such as creativity with digital tools.

Maker-based education and creativity

Taking into perspective creative computing (Brennan, Balch, & Chung, 2014) and maker culture approaches (Dougherty, 2012; Peppler, Halverson, & Kafai, 2016) developed in an increasing number of formal and informal settings in recent years, we consider creativity as a process that could be supported not only by computers but also by diverse digital technologies, such as robotic components. Learning-by-making, which drives the Maker movement, is a creative computing approach aiming to engage the learners in the construction of digital and tangible artefacts through the use of technologies (Martin, 2015). Maker activities provide an opportunity for the development of interests, identity, and content area knowledge (Martin 2015). Through maker-based project activities, participants can be engaged in constructionist activities based on developing an idea and then designing and creating an external representation of that idea (Y. B. Kafai & Resnick, 1996; Papert & Harel, 1991; Sheridan et al., 2014). According to (Mclaren, Stables, & Bain, 2006): "the articulation and externalisation of personal and creative thinking from the 'minds eye' to a tangible outcome is a central issue when engaging in design activity". Maker-based education could therefore be considered as a form of design-based learning in which the learners are engaged in modelling and prototyping a physical, and often digital-enhanced, artefact. According to Vossoughi and Bevan (Vossoughi & Bevan, 2014), there are three major impacts that making has had on student development: fostering and supporting students' participation in science environments, supporting academic/disciplinary development, and creating communities of learners. While learning by creating artefacts, learners can also develop 21st century competencies, such as creative problem-solving (Katterfeldt, 2014). Maker activities are not focused on digital technologies but on design-based approaches of creating an artefact to provide a solution. In makerspaces or fablabs, the technology is not the focus but rather a tool for creating and innovation. Technological tools are pedagogically relevant when they offer added value for the learner educational experience. Educational robotics, for example, provides the learner the opportunity to work in an interdisciplinary context where coding, engineering, mathematics, design, and science concepts can be learned (Eguchi, 2014).

Maker education is "an education approach that positions the student as an innovator with the responsibility to find solutions to relevant problems" (Wiebusch, 2016, p. 1). In maker education, the creative process is as, or even more, important as the final product (Gerstein, 2016). The importance given to the creative process in maker education could help address a problematic in assessing creativity: creativity assessment is often too focused on the outcomes than on the process (Mclaren et al., 2017). Maker activities are driven by the learner's interest and can support curiosity and inquiry while creating with tolerance for failure and retrial and encourage peer collaboration (Oliver, 2016). The maker movement culture based on sharing, autonomy, iteration giving, participating and supporting (Barma, Romero, & Deslandes, 2017; J. D. Cohen, Jones, Smith, & Calandra, 2016) could facilitate the emergence of creative processes and outcomes. Making can contribute in empowering learners and develop a greater sense of possibilities to engage and shape their future (Agency By Design, 2015). Jankowska & Atlay, (2008) highlight the positive effects on student engagement that can be fostered by creative learning spaces such as the makerspaces or fablabs. Makerspaces are open to do-it-yourselfers of varied backgrounds and ages. Maker space activities that combine digital technologies with crafts and more traditional technologies such as a sewing machine can therefore require a variety of competencies and skills that can be attained through the collaboration of younger and older learners. Using maker spaces for joint projects requiring both experience-based and technological know-how could be an opportunity not only for different types of intergenerational learning but also for achieving the goal of inclusive design and the development of an innovator and creative mindset**.** Jefferson and Anderson (2017) highlight the potential of maker activities, both in formal and informal, learning contexts to foster creativity (Posch & Fitzpatrick, 2012), but also other key competencies for the 21st century such as collaboration and problem solving. Learning by making encourages learners to understand how technology works, rather than be satisfied simply consuming technology (Y. Kafai, Fields, & Searle, 2014). Learning by making activities therefore provides opportunity for learners to co-create with technologies which has been argued by (Romero & Laferrière, 2015) as a more advanced usage of ICT than simply consuming them. In maker activities, teachers usually serve as facilitators or learning guides by modelling, asking questions, collaborative play, and explaining how tools work (Brahms, 2014; Gutwill, Hido, & Sindorf, 2015), which corresponds to the teacher's role in other pedagogical strategies where the student is active. In order to help pre-service teachers integrate maker education in their teaching practices, Cohen (J. Cohen, 2017) stresses the importance of integrating maker activities in the pre-service teachers' curriculum to increase their self-efficacy relative to learning and teaching with maker technologies.

#SmartCityMaker (FabVille), a techno-creative project

The #SmartCityMaker is a research project that aims to develop learners' 21st-century competencies, such as creative problem-solving, by proposing a theme-immersed techno-creative project in which learners are engaged in a learning-by-making approach through co-designing and co-constructing pedagogical sequences exploiting a model of a city. #SmartCityMaker is a pedagogical sequence where technology is used to foster learners' design thinking (Bowler, 2014) by placing learners in a complex task that requires a high level of creativity. We consider that learners are required to reach a high level of creativity because they are asked to address a complex educational issue by creative use of ICT. For example, one team chose to address the issue of dysphasia in class by creating a pedagogical sequence that meets the needs of dysphasic children with creative use of ICT. #SmartCityMaker also adopts an approach that offers digital resources that are combined with a tangible model of a smart city.

Figure 1. Construction of the smart city model.

The combination of digital and tangible objects could offer an opportunity for learning through embodied cognition (Wilson, 2002) as learners are able to physically interact with the pedagogical artefacts. Wilson understands embodied cognition as "the idea that the mind must be understood in the context of its relationship to a physical body that interacts with the world" (p. 625). Indeed, knowing that learners have a limited working memory capacity, it is stressed that dividing the cognitive load imposed by the learning task through different subsystems of memory could prevent negative effects from cognitive overload (Baddeley, 1992, 2012; Chandler & Tricot, 2015). Moreover, gestures can help reduce cognitive workload, therefore, freeing resources from working memory load that can be used in order to create deep understanding (Chandler & Tricot, 2015; Glenberg & Robertson, 1999; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). Intertwining craft with digital artefacts could foster learners' engagement in complex programming concepts and practices that could help develop 21st century competencies such as creative computational thinking. As constructing a city model in the classroom and creating a pedagogical sequence are complex activities, it requires a certain number of sessions to be completed. In the first (few) sessions of the project, the #SmartCityMaker is constituted of activities, which are developed with a higher degree of teacher regulation. The first activities engage learners as city planners, and each small team should define the urban standards and the theme to design and build the building in their neighbourhood. Design thinking approach (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013) is central to the conception and construction of their building model as learners need to respect individual and collective criteria, therefore complexifying the building activity and relying on creative problem solving. The models need to respect a specific scale, to be made in low-cost or recycled material, clearly express the team-chosen theme, to be solid enough so can be transported each week. The building process and results are first assessed in formative way to allow learners to modify components of their building that are lacking in coherence and creativity. In this initiation phase, students are organised in teams based on their level of confidence in the use of ICTs in order to ensure teams are homogeneous from this perspective. The first activities aim to develop team building (forming and storming) and the norming stage (Tuckman & Jensen, 1977). Norming is orchestrated through the urban rules definition task where teammates decide together how they will work as a team and what the urban rules of their neighbourhood in the #SmartCityMaker project are. Buildings are assembled within the team, and the different neighbourhoods are merged at the end of the second session of the course. The second part of the project is carried out in parallel through team-based projects by students. As previously mentioned, each team is required to address an educational issue that they may face in their career and to analyse it. They are then asked to design a pedagogical intervention considering Technology Enhanced Learning (TEL) possibilities. The students are then asked to anchor their techno-creative pedagogical sequence within the theme of the city model. Concretely, students could implement ICT in the city model in order to pedagogically exploit them. For example, one team developed a sequence where students would have to make robots circulate in the city in order to develop mathematics concepts. Subsequently, students are invited to discuss the educational limit of their activity and the potential transferability of the activity in another educational context. Figure 2 introduces the different phases and tasks within the #SmartCityMaker project, which combines both guided tasks and autonomous project-based responsibilities within a co-design and iterative approach (Bowler, 2014).

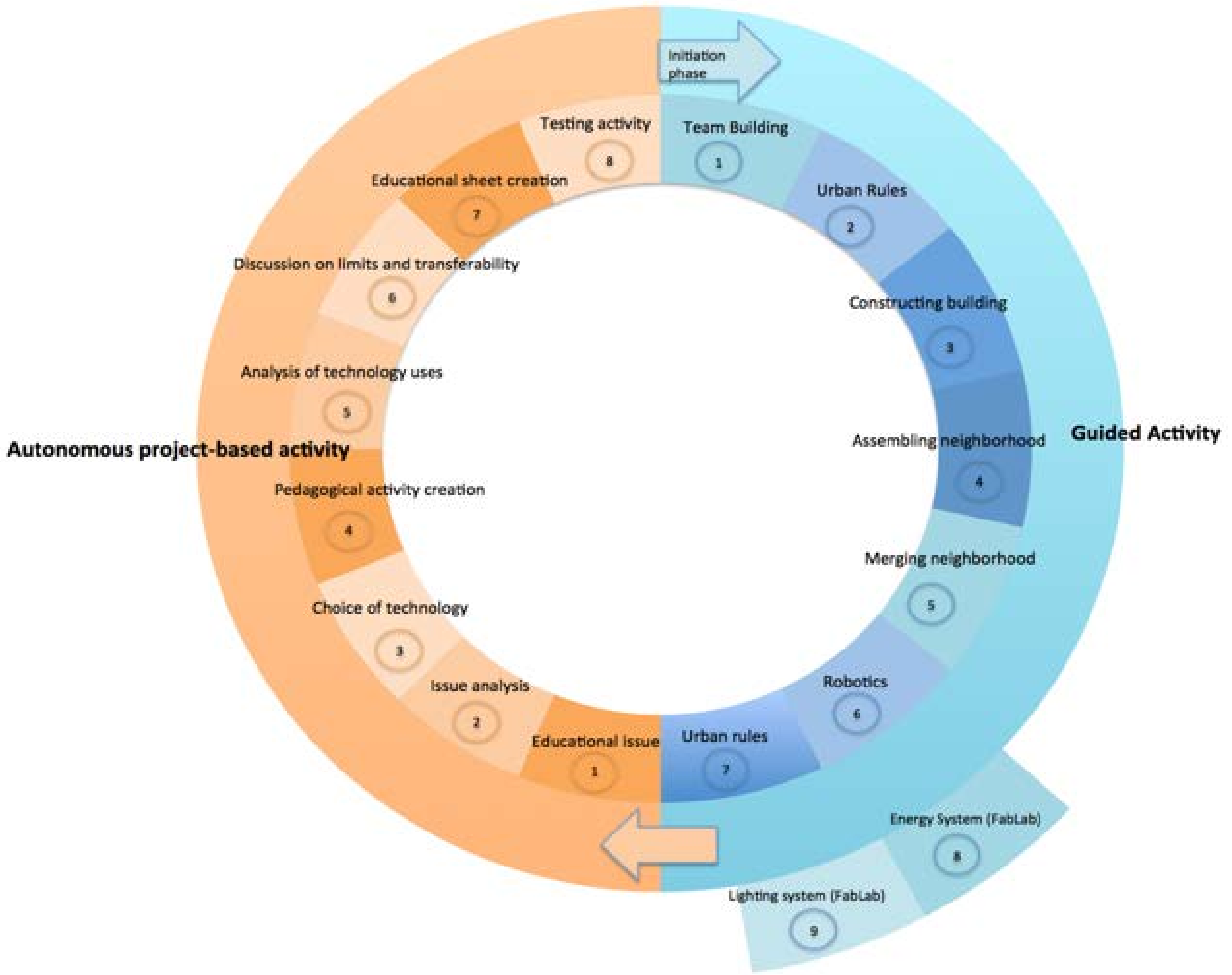

Figure 2. #SmartCityMaker iterative process

The city theme has been chosen by its potential to build on the city model through interdisciplinary projects. Cities are complex systems, which engage all the curriculum disciplines at different stages. From geography technics for being able to read and transpose a plan, to history and mathematics required to reconstruct a building, all the disciplinary objectives of the Québec curriculum (PFÉQ, Gouvernement du Québec, 2011) can be related to the city theme. Moreover, the concept of a smart city "as a city that uses digital technology, data analysis and connectivity to create value and address its challenges" (Feder-Levy, Blumenfeld-Liebertal, & Portugali, 2016). The smart city theme offers a large diversity of possible projects, which requires digital solutions to improve the problems identified by the students in their daily lives. Within the #SmartCityMaker class-based projects, students are invited to develop small team projects to integrate urban sciences, logistics, geography and history concepts as well as Science, Technology, Engineering, the Arts and Mathematics (STEAM). The city model can be a construct based on a real city, therefore offering different geographical issues to explore through the city's construction or can also be an original creation designed from scratch by the learners. #SmartCityMaker values the use of ecological and recycled materials as well as the use of already used materials in the building model construction over the use of new materials. As (Tanenbaum, Williams, Desjardins, & Tanenbaum, 2013) argues, maker activity is determined by prevailing ethos of "making is better than buying. Furthermore, #SmartCityMaker also seeks to use low-priced digital resources alternatives with equal pedagogical value instead of expensive resources. Creating

#SmartCityMaker projects with affordable digital resources have the possibility to increase the transferability and implementation odds of such a project in disadvantaged areas.

Figure 3. #SmartCityMaker activity in Québec FabLab.

Collaborative research approach (Desgagné, Bednarz, Lebuis, Poirier, & Couture, 2001; Wiske, Educational Technology Center, & And Others, 1988) is valued through the #SmartCityMaker project. Pre-service teachers of Université Laval (Canada), primary and secondary level students from Québec at the fablab *EspaceLab* located at Bibliothèque Monique-Corriveau in Québec City, and volunteers with a high expertise on STEAM collaborate on the project. Collaborative research allows them to test and to prototype some of the #SmartCityMaker activities within the informal learning context of the fablab and then transfer it in a large-scale undergraduate pre-service course at the Higher Education context.

2. Methodology

2.1 Participants

The participants are pre-service teacher students divided in five different groups. All groups were studying a sixth-term course of a Bachelor of Education program for pre-service preschool and elementary school teachers (BEPEP) at Université Laval (Canada). A total of 198 participants (17 men and 181 women) were engaged in the #SmartCityProject within their compulsory course on educational technologies. The course 'ICT uses for preschool and elementary school' is a required course of 3 credits offered at the third year of the pre-service teachers programme. The first four groups attended the Québec city campus while the other one attended the Beauce campus.

2.2 Procedures

There is double perspective assessment of students" creativity in the course. The first one is an individual assessment based on the building process and the result of an urban building model while the second one is a team-based assessment of pedagogical creativity to produce a new and purposeful way to address an educational issue. Students were first asked at the first session to individually build an urban or rural building model for the following week. Their model could be an original creation or a creative replica of an existing building. Each student was assigned to a small team of three to seven students. Each team had been provided with four children's foam mat tiles. Their first activity as a team was to decide the urban rules for their neighbourhood. Teams were required to decide the building norms so that each unitary building model was compatible within the neighbourhood urban rules defined by the team. Urban rules included the model scale. For example, a team had decided to build their models on a scale where one centimetre of the model represented one metre in reality. While coordinating the activity, teams had to ensure that every building model fitted on provided foam mats. Each student was engaged to design and create a building according to the team urban rules as homework. During the second session, each student brought their building model in order to create and design their neighbourhood on the foam mat. Before assembling the building on the foam tiles, each team was asked to plan and draw a road within their neighbourhood and to interdependently coordinate their roads with other teams to ensure that all neighbourhoods were connected as a city. After the city model co-design, each team was asked to find an educational issue that interests them. After choosing their educational issue, students were asked to justify its relevance and analyse it by referencing scientific literature. Students then had to create an interdisciplinary pedagogical sequence that integrated collaborative and creative uses of digital technology that was going to be evaluated in a team-based assessment. The pedagogical sequence also had to revolve around the theme of the city so that elements could be physically integrated in the previously built city model. The city theme has been chosen by the potential for interdisciplinary projects to build on the city model. Cities are complex systems, which engage all the curriculum disciplines at different stages. From geography technic for being able to read and transpose a plan, to history and mathematics required to reconstruct a building, all the disciplinary objectives of the Québec curriculum (PFÉQ, Gouvernement du Québec, 2011) can be related to the city theme. Moreover, the concept of a smart city "as a city that uses digital technology, data analysis and connectivity to create value and address its challenges" (Feder-Levy et al., 2016, p. 2). The smart city theme offers a large diversity of possible projects, which requires digital solutions to improve the problems identified by the students in their daily lives. Exploiting a rich theme such as the smart city could serve as breeding ground for creativity development intertwined with curriculum knowledge acquisition. Subsequently, students were invited to discuss the educational limit of their activity and the potential transferability of the activity in another educational context. Finally, each team was asked to conduct an in-class pilot of their pedagogical sequence so that they can get feedback from teachers and peers based on actual practice. The process from abstract research to concrete pedagogical practice echoes Davydov's concept of "ascending from the abstract to the concrete" that is used in activity theory. (Davydov, 1988; Engeström, 2005) or the concept of reification in computer sciences (Afshari & Su, 2016).

2.3 Assessment of Creativity

In order to collect the learning process at the team level, we use team-based diaries. Huang (Huang, 2005) cited Nunan (Nunan, 1992) and mentioned that learning diaries have been described as important introspective tools which provide researchers with great opportunities to explore learners' own perceptions of learning. The CSCL process is documented by the students through a team-based diary in which the members of the team are invited to write the organisation decisions (roles for each of the members, planning of the different tasks), the creative and productive process of building the different artefacts within the project, to reflect on their learning process and problem-solving strategies during the activities and to integrate photos and videos of their co-creative process. The learning team-based diary is used as a learning tool for students as they are collaboratively demonstrating their comprehension's evolution of educational technology's pedagogical uses. Teachers also use the team-based diary as a qualitative and formative assessment tool by which students receive feedback on their critical thinking competency for pedagogical uses of technology in the classroom. They are also asked to write about the different creation processes done in the course.

To assess each participant's creativity of their building models and pedagogical sequences, we rely on participants' learning journal, focusing on their individual reflection throughout the building process. Learning journals are both self-reflection tool and a longitudinal record of self-declared learning process and outcomes. Learners wrote a learning journal as a means of reflecting on their own thinking, which could support both cognitive and metacognitive process (McCrindle & Christensen, 1995). We also asked participants to take pictures of their building model and team-built neighbourhood from different angles to insert them in the learning diary. Both pictures and text were taken into account to assess students' creativity level in the making of the model. Regarding the assessment of the city model creativity level, teachers collaboratively assessed each building model by grading them according to a rubric-based assessment tool divided in three rating categories from a scale from 0 to 1.7: weak, good and excellent. The assessment was based on creativity criteria based on Cropley, Kaufman and Cropley (2011) and adapted to the curriculum creativity criteria of PFÉQ by Romero and Vallerand (2016): exploring new solutions, using inspirational sources to guide creative research and select a solution while considering context. The three components were separately assessed and then merge to create the grade from 0 to 1.7 points. The average grade for all 198 students was 1.5345 (sd=0.29). We choose to assess creativity with a rubric-based tool as they have shown potential in identifying the need for improvements in project-based learning and facilitate valid judgement for complex competencies when clarity and appropriateness of language in the tool is a central concern in the elaboration and sharing of the tool (Jonsson & Svingby, 2007; Reddy & Andrade, 2010). Therefore, we have previously shown and explained each grading category and their key words and gave students project examples from previous years that obtained an excellent grade so they could better understand teachers' expectancies. As the educational context required teachers to assess student production in less than two weeks, not every student work was double assessed. However, teachers were grading in team when they remotely had a doubt about the valid judgement of a production. Below are examples of students' reflection and building model. Data was analysed deductively as teachers were analysing manifestations of creativity criteria according to Cropley et al. (2011) adapted by Romero and Vallerand (2016) of the creative process. Regarding the assessment of creativity of the pedagogical sequence, teachers also used a rubric-based assessment that had five criteria including creativity decided to have a holistic assessment. They collaboratively assessed a grade on 20 points. This grade included creativity, analysis of the educational issue, overall quality of the document, in-class pilot and pedagogical plus-value of the sequence. The average grade for all 197 students was 18.268 (sd=0.74). Examples reflect the average grade as most were granted a high creativity grade. The first example, in the building model activity, shows a student displaying creative and design thinking skills in the building process as she engaged in a search to find the best adapted material for her building model. The second example, in the pedagogical sequence creation process, shows collaborative creativity as students are diverting the intended use of a Sphero robot in order to address the need of kids with dysphasia.

During the first session, our team decided that western-themed would be our urban norms. One of the difficulties that I encountered during the construction of the building model was the choice of material because the building model had to be detachable. Thus, I chose to use cork planks as well as Velcro. What was particular, though, was the material manipulation; cork being too delicate to manipulate once it is cut. It was therefore decided that exterior facing would be made with wood planks or with bricks. After doing the base of my building model, I painted it and then I used little wooden branches that I sawed.

In order to help students develop an understanding of fractions, we propose that they co-create and co-design a video game about fractions with *Learningapps.* In order for students with dysphasia to develop creativity, we agreed that they would be asked to program a *Sphero* robot that would circulate around the city model in order to help them understand the concept of angles in mathematics. The students could then film themselves explaining their creation process in order to develop their communication skills in a stress-free environment.

Figure 4. Projects with a high creativity grade

During the course, teams also had to carry out a 20-minute simulation of their pedagogical sequence in front of the other students in order for the audience to understand the main learning mechanics of their sequence. The simulations were assessed through a peer-reviewed process where each team was assessed by every student watching their simulation. This peer-reviewed process criteria, including creativity, were the same as the one teachers used to assess each pedagogical sequence. The teachers explained the criteria the students and made sure that nobody had any questions on the interpretation of selected criteria. Each student was asked to assess the creativity of pedagogical sequence in rubric-based assessment divided in three levels: “the project is not creative and not coherent with the intended learning outcomes (N1)”, “the project is somewhat original and coherent with intended learning outcomes (N2)" and "the project is creative (N3)" (see figure 5).

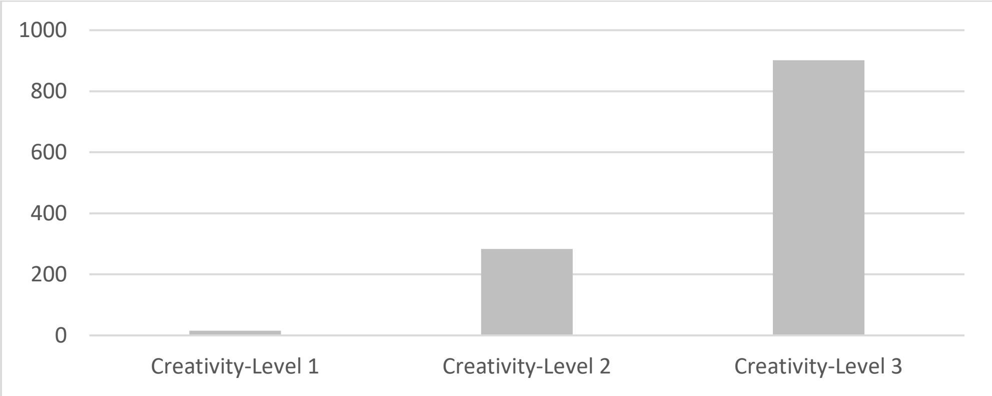

Figure 5. Peer-assessed creativity

We noticed a small difference between assessments from teachers and peers as there was more N2 project assessed by peers than N2 projects assessed by teachers. Peers were therefore slightly more severe than teachers in the assessment of creativity.

Acquisition of content-related knowledge of pedagogical uses of educational technologies was assessed through a final exam where students had to answer three questions. In the first one, students had to give five examples of creative and collaborative pedagogical use of technology. Assessment of the first question was rubric-based composed of four criteria: collaboration, creativity, identification of pedagogical plus-value of and identification of pedagogical limits. In the second question, students had to identify two 21st century competency for both teachers and students and argue why the selected competencies were important. Assessment of the second question was rubric-based composed of two criteria: the quality of the argumentation and the use of scientific sources. In the third question, students had to identify and explain two pedagogical plus-value and two pedagogical limits of using coding in class. Assessment of the third question was rubric-based, composed of four criteria: identification of pedagogical plus-value of and identification of pedagogical limits, the quality of the argumentation and the use of scientific sources. As the educational context required teachers to assess student production in less than two weeks, not every student work was double assessed. However, teachers were grading in team when they remotely had a doubt about the valid judgement of an answer. The average grade for students (n=199) was 90,7298% (SD=10,66).

Discussion

In the current Québec educational context, competency assessment is integrated in the official curriculum (PFÉQ, 2011) but is still not fully implemented into teachers' practices as it is still criticised in the public sphere as being too complex to be fully understood by teachers. Thus, it is important to provide teachers with pedagogical projects that underline 21st century competency development such as creativity (Wegerif, 2006). Projects such as #SmartCityMaker offer a possible solution to this issue as it provides fun, tangible and concrete projects while also articulating a high level of complexity where 21st-century competencies can emerge. Considering students' ability to show a high level of creativity and design thinking skills in the model building as well as in pedagogical sequence creation activity while also being able to acquire and understand content-based knowledge such as 21st-century competencies, coding, robotics and digital games, we therefore argue that a maker-based pedagogical design can support creativity without jeopardising the acquisition of knowledge. The maker-based activity has to be designed in a way that students can have a creative margin in the process and results while also feeling the need to acquire content-related knowledge in order to create their solutions. In our maker-based activity, we induced students' need to acquire knowledge about educational technologies by engaging them in an inquiry about authentic educational issues in which they had to propose a creative and original way of addressing their selected educational issue. Moreover, # Conducting #SmartCityMaker with pre-service teachers also prepares them for 21st-century teaching practices (Häkkinen et al., 2016), as it helps foster learners' collaborative creativity (Romero, Hyvönen, & Barberà, 2012) as well as collaborative problem-solving. We therefore think that #SmartCityMaker has a high transferability potential. Utilising the theme of a smart city allows for collaborative research and practices among scholars from different expertise: urban science (UMR), robotics (*Centre de Robotique et de Vision Industrielles* inc, CRVI), IT advancement (ITIS) and educational psychology. Although collaborative creativity is encouraged through #SmartCityMaker, we did not provide a framework of creativity to participants during session to help them conceptualise what our definition of creative building model was. Participants having a thorough understanding of creativity might have helped them build models with a higher creative value. Also, while participants received a written notice informing them that they would receive an assignment on the first week, they were asked to construct their building model in one week, therefore limiting participants' iterative creation process. Future research should therefore allow more time for the building assignment in order to scaffold creation process. Teachers could also explain some existing creativity framework model in class to foster participants' creativity awareness. Also, as #SmartCityMaker aims to foster collaboration through making, it would be relevant to support collaboration by implementing a sharing platform that would give students the opportunity to share the design process of the project as well as possible multiple iterations (Litts et al., 2016). #SmartCityMaker also offers a tool assessing 21st-century competencies based on a perceptible element that can simplify competency assessment by teachers. Future research should also consider how this tool could allow teachers to identify how projects can foster such competencies and encourage more professors in HE to develop creativity in their respective courses.

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Enduring Learning: Integrating C21st soft skills through technology education

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Abstract

As times change we need to continually review what our education systems offer and where priorities might lie. The Technology and Knowledge Ages of the twenty-first century have brought about new understandings, new ways of doing things, and an array of new career and workplace opportunities. Employees today are expected to bring more than an accumulation of traditional knowledge acquisition. Increasingly important today are a plethora of attitudinal skills and dispositions that enable workers to engage in much greater collaboration, communication, problem-solving, and critical thinking. What are these newly emphasised skills and dispositions and how should they be addressed within the education system? Meaningful learning of these 'soft skills' will occur best in authentic and integrated programmes where explicit teaching identifies the required learning. This paper will investigate the nature of the skills, consider some implications and barriers and then demonstrate connections between the nature of technological practice and 'soft skills'. An essential consideration of this new learning focus is how it might be assessed. A new authentic assessment practice within a Technology Education tertiary education programme is introduced as an example of how knowledge and 'soft skill' acquisition can be combined and achieved.

Key words

Technology Education, C21st skills, problem solving, critical reflection, collaboration, soft skills

Introduction

To be resilient and effective in society today demands a much broader and diversified set of skills and a wide range of behavioural and value-based dispositions than ever before. Ken Kay, President of Partnership for 21st Century Skills (www.p21.org) has identified we are at a tipping point in public education. Significant technological changes and developments in brain and learning research are causing a rethink of the role, content and direction of education in schools (Bellanca & Brandt, 2010). Increased globalisation and the development of a knowledge economy (Gilbert, 2005) have led to a greater need for enhanced cultural understanding, awareness, and empathy, and consideration of a set of different skills, dispositions and attitudes. The nature of today's work environment and requirements from employers demand an increase in flexibility, performance, willingness to take responsibility, and overall capability in an increasingly diverse range of skills. Many academics have called for the need for a more explicit approach to teaching a set of affective or dispositional attributes (Bolstad, 2011; Claxton, 2007, Hipkins, Bolstad, Boyd & McDowall, 2014). Barron and Darling-Hammond (2010) (in Dumont, Istance & Benavides, 2010) identify that students will not necessarily develop an aspiration to analyse, think critically write and speak effectively, or solve complex problems from traditional education practices alone. To effectively learn these abilities specific programmes and approaches will be required. A change such as this will have implications for assessment practices as well. Masters (2013) emphasises that assessment and reporting practices in schools drive classroom teaching and learning indicating that there will need to be a change from the current focus on mastery of traditional school subjects if development of broader life skills and attributes is to be achieved.

Our understanding and perception of knowledge (Gilbert, 2005) has changed and employers are looking more at how prospective employees could otherwise enhance the workforce they will enter by bringing new skills that will complement the organisation's existing structure (Jacobs, 2010). Claxton, Chambers, Powell and Lucas (2011) suggest that mastering of these enduring skills to create robust, resilient, resourceful and reflective citizens with ability to compete for and win places in the workforce should be an important focus for successful teaching and learning programmes. Organisations employing staff expect more than an understanding of the nature and knowledge of the business. To add value to business employees must be adaptable, digitally savvy, and well versed in a range of affective skills and abilities. Significantly potential employees are being interviewed and required to complete a range of psychometric type testing to validate their suitability to the workplace and identify both strengths and potential weaknesses. We might well ask whether our education systems and programmes are preparing learners for this additional and often pivotal challenge. Technology Education is an example of a discipline that provides an excellent platform for the development of a wide range of attitudes and dispositions as well as the development of technological knowledge, know how, and technological outcomes of practice. The creativity, decision-making, discernment, practical applications, and communication required to meet clients' needs and the development of outcomes require a high degree of technological expertise and the consideration of a range of insightful, values-laden and affective capabilities.

It is essential that teaching and learning focus on the explicit development of the 'soft skills' that will withstand times of change and promote new knowledge creation (Bolstad, 2011). Children need to prepare themselves for increased collaborative work, be significantly more engaged in their learning and develop the will and enthusiasm (Riggs & Gholar, 2009) to maximise opportunities. Teachers may need to question their existing beliefs of teaching, learning and assessment to prepare programmes that will allow for a blended approach of content-knowledge and skills, dispositional development and student-led learning utilising a plethora of new-age technologies. Programmes of work in Technology Education are ideal to meet these new demands. This paper will explore the nature of these 'soft skills' to provide insight into how teachers may enhance opportunities for children and students in our schools and consider how assessment practices might need to change to identify future learning needs and give a clearer picture of more holistic student capability. The paper will also highlight how Technology Education programmes can utilise and develop broader skills and dispositions in an integrated manner through problem-solving or inquiry-based pedagogies. Institutions will need to develop innovative and informative assessment and reporting practices (Masters, 2013) to cater for these C21st learning needs and ensure students, parents and caregivers, subsequent teachers, and future employers can evidence the capabilities of these new-age learners.

New-age Capabilities

'Soft skills' have been identified, described, and defined by many researchers (e.g Dweck, 2006; Claxton et. al., 2011, and Hipkins, Bolstad, Boyd & McDowall, 2014), organisations (e.g. OECD, Partnership for C21st, and AC21), and governments (e.g New Zealand's Ministry of Education and the United Kingdom's National Career Service). All have looked to explore future-focussed needs and requirements for twenty-first century learning although the difference between 'soft skills', attitudes and dispositions has not always been clear. Williams (2011) and Claxton, et al. (2011) both see the distinction relating to actions with a tendency towards soft skills and dispositions demonstrating behavioural outcomes. While learners may have an ability and understanding of particular skills they will not necessarily use them consistently, accurately, or effectively. Perkins (2009) believes that people are often lacking in 'sensitivity to the occasion' in that while they may have or understand the skill they are not able to link it appropriately to the situation. Learners must be ready, willing and able to use their skills when the time is right (Claxton et. al. 2011) or as automatic responses to insecure and uncertain situations (Williams, 2011).

Research shows that this emphasis on teaching skills, dispositions and attitudes has gained momentum in order to promote learning and introduce experiences that citizens require to face the on-going needs, changes, and challenges of an increasingly global and technological world.

Wagner (2008) in The Global Achievement Gap, was an early leader in the promotion of dispositions and attitudes for the 21st century, and has advocated seven survival skills that students need to attain:

- Critical thinking and problem solving
- Collaboration across networks and learning by influence
- Agility and adaptability
- Initiative and entrepreneurialism
- Effective oral and written communication
- Accessing and analysing information
- Curiosity and imagination

Claxton, et al. (2011) in their work on Building Learning Power (BLP), have identified four key overarching domains in what they call the 'Supple Learning Mind'. These qualities of mind are the dispositions, and attitudes that effective learners can utilise and which, if they are to be used successfully, need planned intervention (Hattie, 2009).

- Resilience – the learner's emotional and experiential engagement with subject matter including: absorption, managing distraction, noticing and perseverance
- Resourcefulness – embracing the main cognitive skills including: questioning, making links, imagining, reasoning, and capitalising
- Reciprocity – covering the social and interpersonal side of learning and including: interdependence, collaboration, listening/empathy, and imitation
- Reflectiveness – covering strategic and self-managing aspects and including: planning, revising, distilling and meta-learning

Claxton et al. 2011, p. 40-41

In a world of constant and diverse change the ability to be resilient, resourceful, understanding and reflective is incredibly important if citizens are to successfully cope, continue to progress, and respond to life's challenges they will face. There is greater expectation that people will take greater personal responsibility to solve their own problems and although many governments offer support services to help, there is still an expectation that people will use their initiative and awareness to make the first move.

BLP also includes a second framework or *Teachers' Palette* relating to these learning domains and capability dispositions to help teachers develop strategies to assist pedagogical direction and student learning. It includes:

- Commenting – nudging, replying, evaluating and tracking
- Orchestrating – selecting, arranging, target-setting, and framing
- Explaining – informing, reminding, discussing, and training
- Modelling – reacting, learning aloud, demonstrating, and sharing

Claxton et al. 2011, p. 44

The inclusion of these two frameworks in classroom practices will go a long way toward incorporating a culture of learning with a strong emphasis on the promotion of enduring life-long learning.

From a United Kingdom employer's perspective, the National Careers Service (as cited in http://www.nationalsoftskills.org/skills-employers-seek/) include: communicating, making decisions, showing commitment, flexibility, time management, leadership skills, creativity and problem-solving, being a team player, accepting responsibility, and ability to work under pressure as complementing sound technical skills and knowledge as important skills, dispositions and attitudes to complement ability in the particular employment field. These abilities can often determine a candidate's 'point of difference' or provide the competitive edge when qualifications, experience and expertise are similar. Extroverted and socially adept people who can market themselves well are more likely to be successful in competitive situations and will therefore become more employable (Schultz, 2008).

The New Zealand Curriculum (2007) revision acknowledged the rapid pace of social change, an increasingly diverse population, more sophisticated technologies and more complex workplace demands as key drivers for a different approach to developing a curriculum based on what learners need to know and be able to do. To achieve its vision to develop confident, connected, actively involved and life-long learners the curriculum proposes the inclusion of Values and Key Competencies along with eight different disciplinary learning areas. Values such as excellence, innovation, inquiry, curiosity, diversity, equity, participation, ecological sustainability and integrity, and the Key Competencies of: Thinking, Managing self, Participation and contributing, Relating to others, and Using language, symbols, and texts, all strongly link to affective domain soft skill dispositions and attitudes. While these are broad and generic, and made up of many separate components they incorporate a wealth of dispositions and attitudes important to positive, robust, and sustained engagement in society.

An extended 'soft skills' list might also include other aspects such as the following:

Oral and written communication skills	Responsibility	Conflict management
Critical and structured thinking	Honesty/Integrity	Willingness to learn
Problem-solving skills	Following directions	Negotiating skills
Strong work ethic	Creativity	Cultural awareness
Etiquette and good manners	Teamwork capability	Empathy
Organisational skills	Computer literacy	Time management
Courtesy	Self-esteem	Sociability
Professionalism	Reliability	Self-confidence
Inter and Intra-personal skills		

Implications and Barriers

Employers have expressed concerns about how well prepared school leavers are for the workplace (Masters, 2013). An example of how employers see the need for these New-age skills, dispositions and attitudes can be found in a *New Zealand Technology Online* resource (http://technology.tki.org.nz/Resources/Case-studies/Technologists-practice-case-studies/Resistant-materials-hard/Rob-O-Keeffe-Joinery/Pathways-What-Rob-looks-for-in-an-employee). Rob, the owner of a small joinery business proclaims that for him practical skills are not the most essential ability. While experience is important the specific practical work-related skills can be developed over time. Often pre-conceived ideas the potential employee brings can be detrimental to successful assimilation into a business and a degree of unlearning needs to occur before the employee can fully become a member of the team. Rob consistently looks for workers who take pride in their performance, work well in a team, use their initiative, communicate well in oral, written and visual ways, are well-organised with good planning skills, and are able to work independently. He claims… "As a company we're selling ourselves all the time and we need people to be impressed by the quality of our workers."

Clearly Rob is looking for more than practical ability and requires that his workers have a high level of affective dispositions to effectively represent the business. It is important that schools contribute to the development of these wider skills in their programmes so that students' learning better prepares them for work and societal integration. Educators therefore will need to consider how these dispositions are taught, how progress is monitored and how this progress and achievement is acknowledged.

There is a great opportunity within the school curriculum for schools to include these affective and dispositional factors in an open and explicit way to signify their importance and identify that education today is much more than an accumulation of knowledge and technical skill. Students today are going to confront many different challenges than their parents and grandparents may have endured in their working careers and family life and will need this wider range of life skills and dispositions.

These New-age capabilities transcend the traditional model of curriculum where an academically focussed base seemed clearer and where often a dominating perspective was prioritised and certain political ideals prevailed (Bolstad & Gilbert, 2008). Bolstad and Gilbert also suggest that if curriculum extends to shape individual, group, and national identity significant questions will need to be answered about what this might entail. A broader curriculum will require elements of explicit teaching if dispositions and attitudes are to become more than randomly or haphazardly developed in students at school. The curriculum best supporting these attributes and dispositions is vastly different from the traditional nature of learning and action of teachers. It requires a much more student-driven approach and involves significant engagement in rich, inquiry, project and problem-based activity.

Gardner (2006) and Pink (2006) as cited in Bolstad and Gilbert (2008) also note that today's society needs people to be big-picture thinkers, pattern recognisers and meaning makers, and be more right-brain thinkers capable of thinking metaphorically, simultaneously, aesthetically and contextually. They will have an ability to connect with others using a range of well-developed people and relationship-building skills.

A focus on learning rather than performance has significant effects on results in tests (Watkins, 2010 and Hattie, Biggs & Purdie, 1996). The successful development of skills, attitudes and dispositions is heavily reliant and dependent on a positive, respectful, inclusive and encouraging classroom culture. The classroom teacher is required to do everything they can to support and promote programmes that model the practice in what they say and what they do. An appropriate classroom culture must encourage and integrate the physical, cognitive, and socio-emotional environments in play. It is essential that this be inclusive of students in every way with them being of considerable influence in its establishment but obviously led and refined by the teacher.

The new Knowledge Age has seen an advance in the requirement for creative and innovative design of products and services to meet the developing needs of society and to solve the problems that they face. Trilling & Fadel (2009) have identified four powerful forces converging on and portraying life-long learning in this age: knowledge work, thinking tools, digital lifestyles and learning research. Much of this development is now conducted by globally-based collaborative teams and while the ability to master the knowledge and skills required by the practicalities of the work is important, it is frequently more contextualised and acquired within employment. This new skill-set must be utilised by workers as successful employees to cope with the intricacies of an ever-changing world. Fig. 1 demonstrates some of the influences that these forces have had over several generations.

	Anita	Peter	Lee
Work environment	Assembly line 1950s & 1960s Tedious and noisy No qualification	Fascinated by robots Mechanical engineer 1980s & 1990s Designs and installs robotic assembly arms 2008 global financial crisis – new job	Tinkered in design Active environmentalist 2008 designs components for hybrid car solar panels Exciting and demanding work Online collaborative design with a global team
Changes over time	→ More - digital devices - advance technologies being used - collaborative ways of working Work - increasingly less routine and manual - more abstract, knowledge-based, and design-oriented		

Fig. 1 Three generation analogy adapted from Trilling & Fadel (2009)

The shift from 'knowing stuff' to 'doing stuff' requires a wide range of different skills, dispositions and capabilities to be developed. Changes need to be made to create a learning focus that is broad, multi-faceted, engaging and purposeful, and where richer assessment practices will provide students with the formative feedback necessary to acknowledge growth and clarify next steps learning. To best support these changes school curriculum needs to be more interdisciplinary, integrated, inquiry or problem-based. It will engage and excite students through a student-centred paradigm (Snape & Fox-Turnbull, 2011).

Another key development in 21st century understanding is a new focus on the nature of learning development itself. There is a need for wider public awareness of the gap between the kinds of learning students are exposed to and what is actually needed (Bolstad et al., 2012). The most prominent theory of learning today is a socio-constructivist theory. De Corte (2010) indicates that this learning needs to include individualistic acquisition and social participation engagement. De Corte describes socio-constructivist development as learning being; constructive, self-regulated, situated by being embedded in social, contextual and cultural environments, and quintessentially collaborative in nature.

Delors et al. (1996) claim that 21st century learning should be focussed around four fundamental types of learning: learning to know, learning to do, learning to live together, and learning to be. Bolstad et al. (2012, p. 13) see "a need for students to build their senses of identity, become self-reliant, critical and creative thinkers, be able to use initiative, be team players, and be able to engage in ongoing learning throughout their live."

Assessment practices often determine the teaching approach in the classroom (Masters, 2013). In traditional paradigms this has often led to a more didactic teaching style where students are prepared for assessment and teachers become anxious over league table accountability and high-stakes school performance. There is evidence that explicit teaching and learning of key competencies and values acquisition is insufficient, under-valued, and not seen as part of the learning progression (Bolstad, Gilbert, McDowall, Bull & Hipkins, 2012). Many schools continue to focus learning and assessment disproportionately on content knowledge and traditional beliefs about assessment, the transformations we are seeing and needs of future employees are indicating a change of focus to student assessment and disposition analysis is required.

> *"Traditional assessment methods typically fail to measure the high level skills, knowledge, attributes and characteristics of self-directed and collaborative learning that are increasingly important for our global economy and fast-changing world."*
>
> (Griffin, McGaw & Care, 2012 pp. v-vi)

Wiliam (2011, cited in Dumont et al.) ascertains that assessment is central to learning. Feedback will give the learner an understanding of their current abilities and this can then be used to identify subsequent learning requirement or direction. Broadfoot et al. (as cited in Wiliam, 2011) argue that this use of assessment to promote learning depends on: providing effective feedback, involving students in their learning, using assessments to determine subsequent teaching, recognising the influence of assessment on motivation and self-esteem, and students engaging actively in self and peer-assessments. Engagement of these formative assessment practices where there is greater inclusion of the learner in the learning process will require the use of 'soft skills' in which case promotion of, and feedback on the development such abilities must become part of everyday classroom practice.

While many of these implications are beginning to make some traction in learning institutions there remain many forces working against more widespread acceptance of the changes required.

Trilling and Fadel (2009) identify these forces as:

- Industrial Age education policies delivering mass education
- Educational accountability and standardised testing systems particularly measuring reading and mathematics
- Teaching practices based on transmitting knowledge through direct instruction
- Educational publishing companies making income from textbooks
- Educational organisations believing a focus on rigorous content will be undermined by new skills and
- Preferences of parents who learned through traditional approaches and have successful careers.

  It will be important that these forces are considered appropriately to determine what changes may need to made to ensure that dispositions and attitudes are prominent in life-long learning.

'Soft skills' in Technology Education

Design infers a degree of change. This may be some form of development, extension, inclusion of advanced components or invention. Through design, human possibilities are enhanced and expanded, and needs and opportunities are realised. If one relies only on the existing knowledge available how does this development happen? It is clear that many other forces, particularly from the fields of psychology and sociology are associated. The problem-based nature of Technology Education encourages students to employ an array of activities: making judgements, decision-making, critical thinking and emotional actions (Ritz & Moye in Barak & Hacker, 2011). Ritz and Moye go on to state how authentic activity in Technology Education, which is frequently collaborative, provides the relevancy often sought by students in their learning. The multi-disciplinary, attitudinal, and dispositional nature of Technology Education encourages an integrated and meaningful way of learning. The need for students to engage in creativity, innovation, and critical thinking is evident in technological practice. While we often expect students to use these abilities in their work we must ask what we need to do to enhance their ability to do so. Certainly the nature of technological practice will provide opportunities, however students will only improve their ability when new insights are introduced and this requires explicit teaching and wider engagement. Explicit teaching where the students are made aware of the significant learning will help them to grow their existing ideas while contextualised activity will provide the meaningful and purposeful motivation and inducement to engage. Teachers who promote the nature of the significant learning and focus on the reflection and celebration of the learning will help students identify the broader influences and essence of 'soft skill' development.

Kimbell et al. (1991) have provided a particularly clear model of technological practice which explores practice beyond the technical and practical. His reflective/active capability philosophy exposes many of the softer skills employed while developing technological outcomes. Fig. 2 below shows where 'soft skills' can be incorporated into technological practice. Teachers can be active participants in their students' learning and success through utilising the dispositions of the Teachers' Palette (Claxton et al., 2011). Claxton et al. conclude that through commentating, orchestrating, explaining and modelling teachers will assist students in improving their thinking and performance

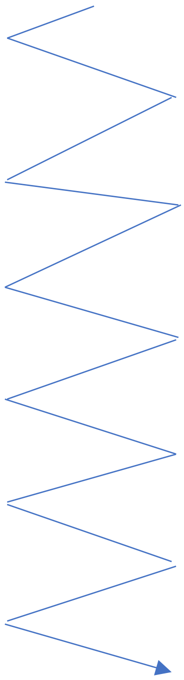
	Reflective Capability		**Active Capability**	
Key Soft Skills	**Imaging and Modelling Inside the Head**	**Scenario**	**Confronting Reality Outside the Head**	**Key Soft Skills**
Problem-solving, professionalism, *self-confidence, responsibility*	Exploring and clarifying the problem or brief		Discussion, stakeholder interviews, visits and research	*Communication, commitment, etiquette, leadership*
Creativity, perseverance responsibility, integrity	Seeking a solution and making value judgements		Brainstorming, existing ideas, product evaluation, planning	*Organisation, work ethic, teamwork, time-management*
Willingness to learn, reflection	Hazy impressions		Sketches, drawings, notes, discussion	*Computer literacy, decision-making, following directions*
Critical and structured thinking	Speculating and exploring		Concepts, early modelling in solid	*Collaboration, negotiating skills*
Reliability, flexibility	Clarifying and validating		Refining models, prototyping solutions	*Decision-making, teamwork capability*
Critical thinking, courtesy	Critical appraisal, evaluation, market research		Developed solutions	*Modesty, self-esteem*

Fig. 2 Kimbell's APU Model (1991): The Interaction of Mind and Hand (adapted by Paul Snape, 2016)

Assessment

The New Zealand Curriculum (Ministry of Education, 2007) states that a primary purpose of assessment is the improvement of students' learning and that this is best achieved as a result of an ongoing interaction between teaching and learning. Evidence of soft skill and dispositional learning is unlikely to be achieved through traditional standardised-norm referenced testing or other high-stakes testing regimes (Reeves in Ballanca & Brandt, 2010). Interpreting students' learning in C21st skills will require more authentic methods that cater for variability, collaboration, and openness.

Reeves identifies that authentic tasks that relate to the student's environment and life are what is needed. He notes that assessment practices need to be developed to identify how students engage in these soft skills, acknowledge how they perform and help students become aware of what they have learned and determine their next learning steps.

Five essential core realms that Reeves sees as important in C21st assessment include what and how they: learn, understand, create, explore, and share. The realms promote a good balance of content knowledge development and consideration of how students can utilise skills to develop a new and important knowledge and understanding of essential dispositions within authentic tasks and developments. Reeves discusses how success in employment today is often seen as team ability rather than individualistic acknowledgement and as such should be represented in assessment through team activity and collaborative performance.

Reeve's view of C21st assessment has been adopted in a new assignment within a Technology Education course as part of an Initial Teacher Education qualification in New Zealand. Students work in pairs on all aspects of the assessment and complete it in parallel with course content development and practice over the ten-week duration of the course. The course itself has been developed using elements from the PTTER Framework (http://technology.tki.org.nz/Teacher-education/Pre-service-technology-education-framework) which includes students developing: an understanding and ability in Technology Education's Philosophy, Rationale, Curriculum and Pedagogy, and Implementation of classroom programmes. The assessment combines knowledge construction, critical reflection, and communication with technological practice. As students engage with the assignment and each other they utilise the full range of 'soft skills' introduced earlier in this article. Aspects of the critical reflection require that they consider the nature of their participation equally with the process and development of their technological practice.

An authentic needs-based scenario is given that presents students with a wide range of opportunities and options for technological outcome development. Students develop a portfolio of their technological practice with interspersed reflections that outline and acknowledge their planning, decision-making, links to knowledge, outcomes, and connection to the 'soft skill' dispositions they utilise. The first two phases of the course cover content relating to the philosophy and rationale for this curriculum learning area. Here each pair develops a construct of what they believe Technology and Technology Education to be and why it is an important part of the school curriculum. In this section they negotiate, question, reason, collaborate, listen, and create their construct. They share this through a forum and are then required to submit a response to the constructs of two other pairs. This requires communication, critique, critical thinking, and interpersonal engagement. Completion of this first part of the assessment requires significant connection to 'soft skills' understanding, appreciation, and participation.

The course then moves on to develop students' understanding of content, pedagogy, and technological practice. This includes engaging with the nature of the curriculum and then the research, planning, product development, modelling, construction, and evaluation phases of technological practice. In parallel the students will work on and evaluate their own practice seeking assistance and further learning as they go. This incorporates an element of formative assessment and an opportunity to continue their understanding and demonstration of the 'soft skills', knowledge and dispositions that will promote better achievement and appreciation for the discipline.

Spaced throughout the portfolio are more opportunities for students to reflect on and identify 'soft skill' and technological understanding as they apply their views of technological practice to their outcomes. Reflections are collaboratively written to promote discourse and consistency of understanding. The students are given a range of reflection tools and ideas to help them unpack their thinking and activity. Two de Bono style 'thinking hats' are introduced to help students consider what their practice means to their own learning development and what implications it may have to how they would perceive or complete it in the classroom. Another technique requires that students validate their learning and practice by linking it to readings and theory introduced in the course. They will also link it to the NZC Key Competencies, Values and Learning Areas (Ministry of Education, 2007) to analyse how their work is connecting to what is deemed important for a well-rounded education in New Zealand. Key Competencies and Values link particularly to the 'soft skills' identified in this work.

In New Zealand a significant aspect of classroom life is the inclusion and experience of bi-cultural perspectives. Bi-culturalism here refers to the relationship between indigenous Māori culture and that of more Western influences (Pākeha). Students learn and practise aspects of Te Reo Māori (language) and tikanga (principles, values, traditions and cultural protocols). The assessment incorporates this with students integrating forms of Māori design into their outcomes and linking their practice to a range of values practised by Māori. These values link especially to 'soft skills' including spirituality, sharing of knowledge, reciprocity, respect and understanding, tolerance, caring, and cooperation.

This authentic assessment practice allows for students to demonstrate their learning, understanding and capability in a way that connects closely to Reeves's view of what is important in C21st learning. Through their participation, reflection, and understanding of Technology Education they can learn, explore, create and share the 'soft skills' and dispositions that are essential for meeting the new needs and requirements of employers and enable them to become robust and resilient citizens.

Conclusion

Significant change is occurring in what employers require of their workers and also in what is needed for people to become resilient, resourceful and responsible citizens able to cope in different times. Education systems must respond to these needs and promote programmes that will best prepare and engage learners. While major change in education policy and curriculum is a high-stakes matter and schools must ensure they are preparing their learners for what they will confront in life and instill a thirst for life-long and expansive learning. Such an approach will require a change to more effective teaching and learning pedagogies, student engagement, and assessment practices. Technology Education is a meaningful and multi-disciplinary activity which can promote active engagement and incorporate a wide range of affective, collaborative and practical skills while requiring a strong sense of problem-solving, creativity and critical thinking. As such it offers the ability to promote the dispositions and 'soft skills' that will make our learners successful participants in society.

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Design, system, value: The role of problem-solving and critical thinking capabilities in technology education, as perceived by teachers

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Abstract

The Organisation for Economic Co-operation and Development (OECD, 2013) defines its views on necessary skills for 21st century citizenship and life-long learning, advocating a generic skillset of literacy, numeracy, and problem-solving in technology-rich environments. Other sources also include critical thinking as a vital 21st Century skill. There are also those who question the concept of 21st Century skills, claiming that, although very important, these skills are in fact old and have been around for decades, or even centuries. Therefore, in many countries, skills such as critical thinking and problem-solving are already addressed in technology education as part of the core subject matter, especially regarding competencies connected to technological literacy. Critical thinking and particularly problem-solving have been well researched in technology education, but seldom from the teacher's point of view.

The aim of this article is to investigate Swedish compulsory school technology teachers' views on problem-solving and critical thinking as curriculum components and as skills addressed in teaching. Twenty-one teachers were subjected to in-depth qualitative interviews. The findings of the study show that the interviewed teachers can be said to express three approaches to teaching about technology in a critical thinking and problem-solving mode: (1) the design approach, (2) the systems approach, and (3) the values approach. Even though the present Swedish technology curriculum does not explicitly mention these skills, the teachers say they incorporate critical thinking and problem-solving in different settings within the subject of technology. Problem-solving and critical thinking are not seen as generic capabilities but they are always connected to, and integrated with, subject content in technology by the teachers. The teachers mix the approaches depending on the teaching content, especially when teaching about complex technology, although there is a tendency to disregard critical thinking capabilities when dealing with design, and neglect problem-solving skills when addressing values.

Key words

problem-solving; critical thinking; technology education; 21st century skills; design; system; value; technology teachers; Sweden

Introduction

The Organisation for Economic Co-operation and Development (OECD, 2013) defines its views on necessary skills for 21st Century citizenship and life-long learning, advocating a generic skillset of literacy, numeracy, and problem-solving in technology-rich environments. Other sources also include critical thinking as a vital 21st Century skill (Binkley et al., 2012). There are also those who question the concept of 21st Century skills, claiming that, although very important, these skills are in fact old and have been around for decades, or even centuries (see, for example, Kirschner, 2015).

In many countries, therefore, these skills are already addressed in technology education as a part of the core subject matter, especially regarding competencies connected to technological literacy (Avsec & Jamsek, 2016; Jones, Buntting & de Vries, 2013; Pearson, 2007; Pearson & Young, 2002). Although hidden under different labels, 21st Century skills have been part of the Swedish technology curriculum for the compulsory school for the past decades as core capabilities such as critical thinking and problem-solving. The current Swedish curriculum for the subject of technology focuses on identifying problems and finding technological solutions to these problems, as well as critical analysis of modern technology usage and its everyday interaction with people and society (Skolverket, 2016). The curriculum is also in line with research in the philosophy of technology, where problem-solving and critical thinking are seen as central to technology activities (e.g. Mitcham, 1994; Ropohl, 1997).

Problem-solving is consequently an essential feature of technology education. Indeed, it can be said to be part of almost any technology learning activity in primary and secondary classrooms around the world. Therefore, the research in this area of technology education is substantial, from the origins of the field in the early 1990s and onward. During the 1990s, McCormick and his team investigated the nature of the problem-solving activities that students engage in during “design and make” projects in design and technology (D&T) classrooms in the UK. One important finding was that students need a varied set of approaches at different stages in the design process (Hennessy & Murphy, 1999; McCormick, 1995; McCormick, Murphy, & Hennessy, 1994). Hill explored design and technological problem-solving in real-life contexts in some projects in Canadian primary and secondary schools (Hill, 1998), and concluded that these design processes were dynamic and creative, and students could put technology in a societal and environmental context. In a Finish study, Lavonen *et al.* studied problem-solving in a teaching experiment where eighth-grade students used programming tools in a control technology project (Lavonen, Meisalo, & Lattu, 2002), and found that the majority of learning processes were collaborative. Mioduser & Kipperman investigated specifically the evaluation/modification phase of a design and problem-solving project in an Israeli grade seven class, something which resulted in a more general conception of students’ mental models of problem-solving (Mioduser, 2009; Mioduser & Kipperman, 2002).

In a cross-European project, Hamilton studied primary students working in three groups to develop a solution to a design and technology challenge that originated from within a story context. Teachers intervened to varying degrees in each of the groups, from being largely passive in the first group to being very active in the last, with the latter positively impacting on collaboration, productivity and learning outcomes (Hamilton, 2007). Barak & Zadok and Barak & Assal investigated learning and the problem-solving process among Israeli junior high school students participating in robotics projects; some students were found to be inventive but there were also those who only carried out the most basic tasks (Barak & Assal, 2016; Barak & Zadok, 2009). Castledine & Chalmers similarly explored what problem-solving strategies

Australian primary students employed when working with LEGO robotics, and whether they were able to relate their problem-solving to real-world contexts in an effective way. The researchers concluded that the students were generally able to relate to the real world, and that the robotics activities helped them with this (Castledine & Chalmers, 2011). Middleton studied how students could learn about sustainability in technology education in Australia, and, further, the relevance of problem-solving in this learning. He concluded that the problem-solving approach provides many opportunities to students engaging with ideas of sustainability (Middleton, 2009). Hérold & Ginestié explored in a French context how to make problem-solving in project work in technology teaching more effective, and concluded that this can be achieved by analysing the student's level of understanding of the activity and offering appropriate support (Hérold & Ginestié, 2011).

Critical thinking is also a crucial component of technology education, especially as it is a central skill in problem-solving, but it is nevertheless under-researched and the little research that exists is of later origin. Wells discussed the place of creativity, imagination and critical thinking when designing, and concluded that design and problem-solving cannot be confined to a limited set of prescribed steps (Wells, 2013). Yu *et al*. studied how Taiwanese senior high school students apply conceptual knowledge in order to think critically when learning the history of communications technology. The researchers found that although the students displayed various misconceptions, for example, concerning systems knowledge, students' critical thinking positively correlated with their application of conceptual knowledge (Yu, Lin, & Fan, 2015).

Although primarily focusing on students' work, the great majority of the above studies on problem-solving still point to the importance of what the teacher does by way of instruction and support for successful outcomes of problem-solving activities, regardless of the degree of "student-centredness". How the teacher deals with critical thinking and supports students in acquiring this skill is also considered as very important in the studies on critical thinking. Therefore, it is somewhat surprising that very few studies focus on the teacher and his/her views on problem-solving and critical thinking. Exceptions are DeLuca who studied "best practice" of problem-solving in American schools through a survey about problem-solving activities that teachers thought they had successfully implemented. The findings indicate that technology teachers use teaching methods that promote valuable problem-solving skills, but that they need to ensure that a wider spectrum of appropriate processes and thinking skills are taught (DeLuca, 1991). Mettas & Constantinou explored the influence of working with primary school children in Cyprus on a technology fair on the educational value and meaning attached to problem-solving skills by pre-service primary teachers. The results indicate that the technology fair contributes to improving pre-service teachers' understanding and application of problem-solving strategies within the technology domain (Mettas & Constantinou, 2007). There is still a gap in the literature concerning teachers' views on problem-solving and critical thinking in technology education.

The aim of this article is therefore to investigate Swedish compulsory school technology teachers' views on problem-solving and critical thinking as curriculum components and as skills addressed in teaching.

Theory and Methodology

For this article, the authors analysed interviews with twenty-one compulsory school technology teachers (for students aged 7-16 years old), using a qualitative, semi-structured interview guide (Kvale & Brinkmann, 2014). Each interview was conducted at the informant's workplace, and varied between forty-five and ninety minutes in duration. The interviews focused on exploring the teachers' views on their own teaching within the subject of technology, with follow-up questions regarding specific teaching activities and subject content that the teachers mentioned during the interviews. Problem-solving and critical thinking capabilities were not addressed *per se* during the interviews, but were construed by the authors during the initial steps of the analysis.

In the analysis, we emphasise the teachers' collective experience and views of technology education, and we consider the data as a collective space of meanings. In a sense, this way of looking at the empirical material has certain similarities with phenomenographical analysis, particularly the concept of *outcome space* (Marton, 2014). Thus, the findings primarily reflect the collective breadth of experiences, although in the conclusion we also address the relationship between collective and individual experiences regarding problem-solving and critical thinking.

In accordance with ethical guidelines presented by the Swedish Research Council the respondents were presented with the purpose of the study and told that their participation would be completely voluntary. They were also told that the interviews would be de-identified in regard to names and geographical origin, and that the collected data would be stored safely and would not be used outside the research context.

A dataset was chosen from the interviews containing the teachers' own viewpoints on their teaching about technology when employing aspects of problem-solving and critical thinking. The dataset was then organised and coded using the software MAXQDA. The analysis followed an interpretive process to derive themes from the dataset. By doing so, the authors employed an analytical model based on the hermeneutical spiral and a six-step process of thematic analysis (Braun & Clarke, 2006; Robson, 2002). The authors' combined background experience in teaching technology was used to provide the necessary analytical horizon for the interpretative analysis.

The first step of the thematic analysis was to transcribe the interviews. The authors employed the interpretive process of the hermeneutical spiral by repeatedly reading the material (Robson, 2002). The second step of the process involved an initial coding of interview transcripts using the software MAXQDA. Excerpts of texts were coded using an interpretive approach. Whenever the informants expressed views about their teaching practice that could be explicitly or implicitly related to problem-solving and/or critical thinking, the excerpts were coded with a descriptive code label. The definitions of problem-solving and critical thinking that guided this step of the thematic analysis were based on the literature review above.

The third step continued with a multitude of derived codes that underwent a sorting process to order them into a tree-structured hierarchy. Three themes were constructed by merging codes that were near to or overlapped each other. The fourth step required the themes to be reviewed, revised and refined to minimise the overlap between the themes. The highlighted themes for the technology teachers' narratives were later discussed, confirmed and thereby validated among peers within technology education research.

The fifth step commenced with the definition and naming of the three key themes, bringing out the essence of each theme and the aspects of the data they covered. The themes were: (1) The design approach (design and construction of technology), (2) The systems approach (the complex and networking structure of technology), (3) The values approach (the social and technological implications of technology, for the individual, society and environment). Each theme also contained five underlying sub-themes. The sixth step involved presenting exemplary data of each theme as part of this study's results from the thematic analysis. Illustrative quotes were also translated into English and abridged by the authors in order to increase readability.

Regarding validity, the teachers were not asked directly about problem-solving and critical thinking but were asked rather more general questions about their views of their teaching. Thus, we gave the teachers freedom and space for their own answers, but we also, in a sense, had to construe an analytical narrative on problem-solving and critical thinking with certain themes. Analysis of the data was also peer-reviewed at a research seminar in order to check the validity of the themes. Strictly speaking, our results can only be seen as representative of the twenty one interviewed teachers, but the sample was fairly large and the findings can therefore generate intersubjective understanding of the technology teachers' views. The results of this study therefore point to possible ways that teachers do and can approach problem-solving and critical thinking in technology classrooms, in Swedish and international contexts (Cutcliffe & McKenna, 1999).

Findings

When treated as a collective outcome, the analysis of the teachers' views resulted in three themes of teaching approaches that promote critical thinking and problem-solving skills. The first theme centred on a design approach, focusing on the design and construction of technology. The second theme revolved around a systems approach, concentrating on the complex and networking structure of technology. The main focus of the third theme was the values approach, converging on the social and other implications of technology. Each theme also provided several sub-themes that together defined the specific theme.

The design approach

Most of the interviewed teachers said that in the problem-solving process the production of ideas through creative acts was one of the core capabilities that the students had to learn and develop. Diana explained that the capacity to draw and illustrate an idea was an important step in the design process when constructing a physical model. Alexander mentioned that to construct a physical model or a working prototype includes several stages in the construction process. "To fail and to redo, improve", as Alexander expressed it. One of these steps may include an iterative loop, i.e. returning to revise the drawing or even the idea of the construction if the students find potential for improvement. Felicity extended this approach when she saw a multitude of knowledge areas emerging while working with the design aspects of creating technological artefacts:

> *Then there was this assignment with movement and construction. It was wonderful because we could include technical drawing with drafting and forces […]. The students could observe, for example, that when they added weight their constructed vehicles couldn't tolerate the stress they were subjected to. Then they had to redo their constructions, improve them and so on. (Felicity)*

Isabelle saw great potential in promoting idea creation while working with problem-solving and technological solutions as the students should be able to find solutions when presented with problems in their everyday life:

> *Creativity, not to lose the urge to be curious. The students need to think about everyday solutions from their everyday lives, that is, "Oh, now we have this sort of problem, how can we solve this?" The*

> *student should not be just provided with solutions or given instructions to "do this". The student should dare him or herself to come up with ideas. (Isabelle)*

Furthermore, the interviewed teachers also saw the activity of presentation as a vital step in the design process, as the students present the outcome of the whole problem-solving process to other students – mainly to show that they have managed to fulfil the class assignment but also to receive recognition for their creativity.

Theme	Items	Description
The design approach (design and construction of technology)	• Creativity and idea generation • Drawing and illustration • Construction • Iterative work methods • Presentation	The ability to design and construct technological artefacts through a number of activities; (a) By generating ideas from understanding technological or societal needs or problems, and to use these as a basis for a technological solution. (b) By drawing a conceptual representation of the suggested solution. (c) By constructing a conceptual or working model/prototype for the derived solution. (d) By continuously revising the design activities if there is room for improvement in the design process. (e) By presenting the solution: for example, in the classroom as part of an assignment

Table 1 The design approach

The systems approach

Being able to understand the technical processes as well as how different technological solutions can interact with each other was a core problem-solving element when teaching about complex technology such as technological systems. The importance of understanding how the parts of a system integrate to a whole is something that Leonard focused on in his teaching. He exemplified this in his interview when he talked about the computer as an analogy for a technological system. One essential aspect of understanding is seeing how the computer power supply is distributed within the system. He and other teachers used examples of smaller electricity-dependent technological systems and how they were related to larger electricity distribution systems. In his teaching, the interfacing aspects of systems provided areas for investigation, especially for students using their problem-solving skills to identify possible disruptions of service within a system or in relation to another technological system.

Charlie strove to promote a systems approach when discussing with his students how large technological systems like municipal water and sewage systems coped with distributing both fresh water and wastewater to and from the connected households:

> *I believe that it is all about making the student grasp the concept of [...] how [technology] is connected and things function out there in society. I mean, these [large technological municipal systems] for garbage and water - how do they actually work? How does [the fresh water] get from*

> *the lake to the households' faucets? And the garbage, what happens to it? I think that [the students] should have this knowledge, because then - well - it makes it easier for the students to engage in recycling if they, quite frankly, know what happens. (Charlie)*

Nelson also used the computer as a kind of system model, and focused on the need to know the interchanging flows of information between the computer user and the computer itself in order to problem-solve in a digital setting. The human-machine interface provided several important opportunities for critical thinking, which was something that he further elaborated upon when he talked about a system's outputs and the effects on individuals, society, and the environment.

The interchanging processes between different components within a system were something that Kate also focused on in her teaching. Peter extended this to include also an opening of the "black-box", i.e. the outer exterior of a system. By doing so, the interior of the system becomes accessible to the student for the purpose of critically evaluating the importance of individual components and how they affect the system's processes, and in particular the outputs of the system.

George explained further in his interview that knowledge about how complex technology interconnects provides the student with tools for navigating a technology-enriched world. The student will thus be able to perform simple, yet essential, problem-solving tasks when dealing with certain parts of a technological system:

> *The students should understand how things work and how to use tools, as they are expected to manage themselves when school is finished. The students should be able to change a plug, understand why it is a plug and why they should not replace the plug with a nail to get the electricity working again in the household. They need to understand cause and effect. They need to understand the world around them and they need to acquire the skills to be able to influence it. This could mean to understand an electrical system, and to be able to use it in a sensible way.*

Theme	Items	Description
The systems approach (the complex and networking structure of technology)	Black-box Micro-macro System interfaces (input/output) Networking parts and components Processes	The capability to understand and critically evaluate technological systems from a number of viewpoints based on identifying key elements of the system: (a) By observing the physical structure of complex technology, such as technological systems, through opening up the black-box that encompasses the system in order to critically investigate the internal structure of the system. (b) By observing a technological solution or a system through its different parts and its whole structure so that the overall functionality is observable. (c) By identifying and observing the interfacing components of a technological system to determine how the system interacts with its surroundings, i.e. what enters the system by its input(s) and what exits the system by its output(s). (d) By observing and identifying the networking parts and components within a technological system. (e) By identifying and observing a system's processes and the impacts on the system's functions that (changing) different components can have

Table 2 The systems approach

The values approach

Understanding technological change was something that the teachers found to be a core ability when critically analysing and evaluating technology. The temporal understanding of a technical solution, i.e. historical background, present-day status, and the possible future development, was considered especially important. Peter made a point of this in his teaching, where the students, after understanding the reason behind a technological solution, also continued to challenge their own thoughts about technological development. Quentin found it necessary for the students to be able to discuss implications for society, environment and individuals. This was something that other teachers in this study exemplified with technological malfunctions, such as problems in filtering in a sewage plant or the failure of a fuse in a domestic setting.

The social aspects of ethics and moral values were also important for critical thinking capabilities, according to the teachers. Kate introduced this in her teaching by discussing fairness with her students, for example, asking whether every human has the right to drink filtered, clean water. Ursula took it further by making the students question the need for cheap clothing if child labourers manufacture it. Some of the teachers found these kinds of discussions relevant when comparing and evaluating different sorts of technological solutions. In Alexander's and Oscar's teaching, qualitative comparisons of various technological innovations such as bridges, household appliances, and digital technology were things that they focused on. Nelson explained in his interview that the students should be able to question what is important regarding technological development – and for whom. The students should be able to question whether certain technological solutions should even "exist" in regard to personal integrity:

> *I believe that it is really important that the researchers and technicians in the future know how to answer the question of "Who or what is going to be in charge?". Will it be just the money or will it be...? Well of course money will be an issue in the future, but at what cost? It is really important that you are aware of such things and able to participate in a discussion about such things in school. We [the teachers] help to make students think and reason about such issues. I believe that it will be even more important to do so in the future. For example, I'm thinking about the technology behind 'transponders', that it is possible to track every single human and their position. Do we want to have [a society] like that? How can [technology] be abused and so on? (Nelson)*

Ursula strove to empower her students when teaching about the consequences of technological development, and tried to show them that they as individuals possessed the ability to influence industries to rethink their business strategies when they as consumers placed certain demands on the product they wanted to purchase:

> *Today I can say that I want a car that is better for the environment, that needs to consume less fuel. That's what I want, and that's what I want to buy. Then I am able to influence as a consumer the entire automotive industry. (Ursula)*

Additionally, the teachers in this study also included problem-solving discussions about efficiency when comparing different solutions. However, regardless of the characteristics of a technological solution, the teachers also mentioned the importance of recognising the human agent in technology, as Oscar explained in his interview. He further developed this thought by saying that humans are the catalyst for technological change as humans define needs and act on them to develop solutions.

Theme	**Items**	**Description**
The values approach (the social and technological implications of technology, on the individual, society and environment)	Then-now-future Implications for the individual, society and the environment Ethics and values Comparison and valuing of results The human agent	The ability to analyse and evaluate technology through a set of inquiring activities; (a) By acquiring a temporal understanding of the technological solution's development throughout history and in the future. (b) By identifying the solution's implications on the individual, society and environment. (c) By a value-based questioning of the solution from a moral and ethical viewpoint. (d) By comparing and evaluating different solutions, as well as the results of each solution. (e) By identifying and explaining the role of humans as agents and developers of technology

Table 3 The values approach

Discussion

In this study, the authors examined how technology teachers within the Swedish compulsory school perceived their teaching when including critical thinking and problem-solving capabilities. The analysis shows that the interviewed teachers used different types of technological contexts, in particular through three approaches; (1) the design approach, (2) the systems approach, and (3) the values approach. An interesting note is that these approaches were mixed by most of the interviewed teachers when teaching about particular areas of technology. For example, Kate used two of the approaches when she used the local sewage plant as a teaching object and discussed the plant from both a system (focusing on the system's structure and function) and value (primarily the system's implications) perspective.

The design approach

Understanding and design of artefacts take up a considerable part of the overall teaching about technology in Sweden (Bjurulf, 2008) as well as in other countries (de Vries, 2005; DeLuca, 1991; Jones, Buntting & de Vries, 2013). This way of teaching harmonises well with being technologically literate, i.e. being able to understand that technological solutions originate from the designer's ability to identify and transform needs into ideas and after that into concrete artefacts (Ingerman & Collier-Reed, 2011; Wells, 2013), which also corresponds with the informants' self-confessed desire to teach students creative methods for idea generation. The design process adds more value to the expected results if the designer continuously evaluates the working methods and usage of materials when constructing physical models or artefacts (Jones, 1997). As such, being able to communicate ideas and concepts through various models is a vital part of being technologically literate (Compton, 2013; McCormick, 2006). The teachers saw other beneficial effects such as critical thinking skills, problem-solving capability, personal growth and collegial acceptance when the students were able to display their ability to produce something from a design process. The fact that the design process is not linear but involves going back and forth and redoing certain stages was hinted at by the teachers (cf. Williams, 2000), which meant that the structure of the teaching had to be quite student-centred. Similar views were expressed by the pre-service teachers in the Cypriot study, because they had to introduce more constructivist and progressive teaching methods in order to get the design project with the children to work (Mettas & Constantinou, 2007). The present Swedish curriculum for the compulsory school provides details on the design process that corresponds quite well with the interviewed teachers' ideas about how they teach (Skolverket, 2016).

The systems approach

To be able to grasp, critique and solve problems related to complex technology requires a system understanding (Hallström & Klasander, 2017; Ingelstam, 2002; Klasander, 2010; Koski & de Vries, 2013; Williams, 2000; Yu et al., 2015). It was evident from the teacher interviews that the enormous physical size of some systems, such as national electricity distributions systems, hindered students from achieving a clear view of the system's internal structure. Nelson used the black-box model of systems (input, process, output) when teaching about how the systems' interfacing components could relate to individual(s), society and the environment. Understanding the internal functionality of the system requires comprehension of the parts of the system, i.e. the components and sub-systems and their connectivity through different processes (Lind, 2001; Svensson, 2011). This is something that Oscar said he promotes in his teaching by using a micro-macro transition when observing a system. Leonard mentioned that by observing the interconnectivity of systems and sub-systems, the students are able to use their problem-solving skills to identify potential disruptions in connectivity and their consequences. However, when viewing the technology curriculum, the guidelines do not explicitly define what aspects of system understanding the students need to learn. For example, the curriculum does not mention the concepts of input, process and output, which are commonly used in the discussion of technological systems and critical thinking about them (Klasander, 2010; Martin, 1990; Svensson, 2011; Tamir & de Vries, 1997).

The values approach

For students to develop problem-solving and critical thinking skills and thereby achieve a broader understanding of how technology, individual(s), society and the environment relate to each other, they also need an understanding of how to value technology (Keirl, 2006; Stables & Keirl, 2015). Ethics are in the foreground when the teachers present discourses about the consequences of technological choices. Ursula conveys these concerns in her teaching, especially the social impacts of buying cheap clothes from developing countries, and she discusses the consequences for the environment as well as for other individuals. Her main point is that her students need to reflect on how the clothes are manufactured. Ursula thus shows an awareness of the breadth of sustainability as a concept, which in most present-day definitions includes not only environmental but also social and economic aspects. In technology education, there has traditionally been an emphasis on economic issues through a product development culture (cf. Elshof, 2006), but, according to Stables, a more integrated, critical view is needed to fully encompass environmental, economic, social and ethical aspects of sustainability (Stables, 2015). An integral part of teaching about values is also to produce a critical analysis of both human and automation aspects of controlling technology, as Oscar emphasised in his interview (cf. Carr, 2015).

Evaluating technology is a central part of the subject of technology in the curriculum, as consequences of technological choices and adaptation of technology for humans are mentioned in the curriculum. Technological change and implications for individuals, society and the environment are also areas that are firmly established in the curriculum, something which is reflected in the teacher interviews (Skolverket, 2016). The analysis shows that the teachers' ideas about their teaching align with the curriculum in this respect, although the curriculum does not give any detailed guidelines about how to teach or assess these areas.

Conclusion

In conclusion, this study shows that the teachers said they taught about specific technological artefacts and systems, and utilised different approaches at the same time, depending on what was in focus at any given time in their teaching. For example, teaching about certain technological systems such as a sewage plant could involve two of this study's approaches – system and value. This example illustrates the multi-faceted character of teaching about technology and that these approaches are not used exclusively and separated from each other, but rather that the teachers integrate two or all approaches to establish a nuanced learning environment. This is interesting bearing in mind the dominance in particular in the Anglo-Saxon world of problem-solving as design (Barlex & Trebell, 2008). However, this finding also contrasts with the results of a study made by the Swedish Schools Inspectorate that Swedish technology teachers engage a great deal in "design and make" activities without contextual components (Skolinspektionen, 2014). This integrative pedagogy on the part of the teachers is therefore a key finding in this study, and also, in fact, an important pedagogical consideration; a teacher could teach any topic and depending on the approach, students could experience a very different set of expectations concerning critical thinking and problem-solving.

Despite the integrative pedagogy, however, our findings also show a progression of the approaches that might be problematic from a technological literacy point of view. The element of problem-solving is great in the design approach, a little less so in the systems approach, and not prominent at all in the values approach. Critical thinking, in contrast, is not so clear in the design approach but a little more so in the systems approach, and it is very salient in the values approach (see Figure 1). Even though the teachers seem to mix the approaches, it is thus also clear that design lacks an element of critique and that values are not connected so much to problem-solving but rather to broader societal issues, at least as the teachers talked about them (cf. Wells, 2013). This imbalance might be due to teachers' inexperience of addressing problem-solving and critical thinking due to them being implicit in the curriculum, but it may also be, for example, that values have not traditionally been integrated with problem-solving components in technology education. Further research is needed to investigate this.

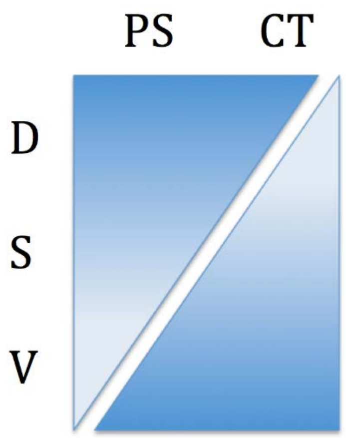

Figure 1. The relationship between elements of problem-solving and critical thinking in the three approaches (D = design; S = system; V = value; PS = problem-solving; CT = critical thinking).

When the teachers in our study said they incorporate critical thinking and problem-solving capabilities as well as other skills like creativity in technology education, they were also contributing to the teaching of 21^{st} Century skills. However, our results show that 21^{st} Century skills are not only seen as generic capabilities but they are always connected to and integrated with subject content in technology by the teachers; it is problem-solving of and critical thinking about *something*, not just a generic capability.

Implications and future research

This study has shown that according to Swedish technology teachers, different approaches can be employed when teaching about technology; the design, the systems, and the values approaches to technology. These approaches can be seen as an interpretation of the 21^{st} Century skills of critical thinking and problem-solving in a technological context. As such, these approaches can be used by teachers when planning teaching in technology as well as by authors designing textbooks and other teaching material in technology education, when the intention is to promote problem-solving and critical thinking together. However, based on the results of this study, for successful implementation of the three approaches it is necessary to pay particular attention to incorporating critical thinking skills when dealing with design and systems, and problem-solving capabilities when dealing with values.

Future studies should explore further how these approaches can be used together with scaffolding techniques to improve primary and secondary students' conceptual understanding of technology in areas such as digital technology and ICT, innovation and sustainable development (cf. Middleton, 2009). The approaches can possibly form the basis for a concrete teaching design that progresses according to the age of the students.

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Action Reflected and Project Based Combined Methodology for the Appropriate Comprehension of Mechanisms in Industrial Design Education

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Abstract

In industrial design (ID) education, mechanics-based courses are mainly based on a traditional lecture approach and they are highly abstract for ID students to comprehend. The existing studies highlight the requirement of a new approach for mechanics-based courses in ID departments. This study presents a combined teaching model for mechanisms mainly based on an applied teaching style and action learning to improve ID students' learning experience and competencies through promoting the transference of theoretical knowledge into practical experience and learning. The combined teaching model, consisting of three phases, was integrated into a design studio project named mechanical game design. A total of forty-one sophomores taking the 'Product Design II' course offered in Gazi University Department of Industrial Design during the second semester of the 2016/2017 academic year, participated in the mechanical game design project. Project observations and a post-questionnaire were employed to objectively analyse the appropriateness of the teaching model. The results indicated that the combined teaching model improved ID students' learning outcomes and competencies in terms of transferring the gained theoretical and practical knowledge into action learning.

Key words

Design education; mechanisms; design studio; combined teaching method; action learning; project based learning.

Introduction

Industrial design is not making things beautiful; it is about far more than how a product looks. As a transdisciplinary profession, it covers many areas, including engineering, science, marketing, aesthetics, and anthropology as well as social, cultural and ecological issues (WDO, 2016; NASAD, 2016; MSU Denver, 2016; ND, 2016; NJIT, 2016). Generally, the students having good skills and competency in these areas are considered to be well equipped for employment. Nevertheless, industry's expectations from ID graduates change with the rapid industrial developments (Liu, Lee, Lin, and Tseng, 2013). Therefore, ID schools should continuously update their curricula and modify their teaching methods according to industrial needs.

The WDO (2016) categorizes three main competencies that design students should be trained in. These are; 1) general qualifications-problem solving, communication skills, etc., 2) specific industrial design abilities and understanding - design thinking, design process, visualization skills, manufacturing, materials, design management etc. and 3) knowledge aggregation.

Many ID departments in Turkey orientate their educational systems and curricula in order to comply with the above-mentioned competencies of their students and they provide multiple courses covering engineering, ergonomics, management, arts, and computer-related areas. Liu et al. (2013) interviewed participants having more than ten years' experience implementing industrial design and teaching and reported that industrial designers must develop professional competencies in eight dimensions; aesthetic literacy, design expression, creativity, planning and integration capability, engineering capability, computer application skills, ergonomics knowledge, and foreign language skills. For the sub-categories (knowledge of manufacturing processes, capability of material usage, knowledge of mechanical designing and principles) of the engineering capability dimension, knowledge of mechanical designing and principles was reported as the most important item. ID students need a considerable understanding of mechanisms in addition to manufacturing processes and material to create innovative ideas. Since the mechanism forms affect both the function and the appearance of the product, it is vital for students to have sufficient knowledge of mechanisms to start a design for a relatively complicated product. To be able to actualise proposed functions for a new design idea, students have to be able to predict which mechanisms could be effectively used. Throughout professional life as an industrial designer, they will be also responsible for the mechanical details of their product designs. However, mechanical design courses generally tend to be taught through traditional methods, mainly depending on verbal lectures. Video-based three-dimensional animations are also not sufficient for design students due to their lack of knowledge of mechanical mechanisms (Liu, Sun, & Wu, 2013). Verbal, visual and video-based lectures are highly abstract for comprehending the practical aspects of the mechanisms particularly when used for the transfer and activation of motion.

Traditional lecture-based education methods, reinforced with proper laboratory activities is generally common and accepted among engineering students. However, design students are hesitant about convergent learning styles and strongly prefer applied learning methods that provide active experimentation, even though they are aware of the benefits of engineering-based education (Bingham, Southee & Page, 2015). The majority of design students are not satisfied with the teaching methods applied to Mechanical Design courses (Bingham et al., 2015; Liu et al., 2013). In addition, Bingham et al. (2015) have reported that according to the outcomes of Final Year Design Practice Projects at Loughborough University, mechanical design and functionality were used inappropriately. Liu et al. (2013) examined 1500 student projects submitted to the Chinese Hardware Products Industrial Design Competition and reported that less than 10% of the students utilised advanced mechanical concepts. The rest of the works were based on styling, which indicates the limited mechanical design ability of industrial design students. Chou and Hsu (2007), indicated that different from engineers, industrial designers rely more on creative problem solving than procedural knowledge, and therefore they need a fundamental training of scientific thinking, in which they may learn how to expand their knowledge domain efficiently. They concluded that, in the long run, well-designed and certificated PBL (problem-based learning) problems for design sciences and technologies can be organized to form a data base, forming a teaching resource for all courses in their department of industrial design.

There is limited research on the engineering-based learning of ID students. However, the existing studies highlighted that design students need a new approach for engineering-based courses and complementary courses and studios that would need holistic perspectives. The aim of this study was to present a combined teaching and learning model for mechanism included products mainly based on an applied learning style together with the functional theory and active experimentation, to improve ID students' practical learning experience. To achieve this, a teaching model, consisting of 3 phases, was integrated into the design studio project (4th Semester) to promote the transfer of the theoretical knowledge obtained in the prior lecture of "Mechanisms" into practical and concrete learning by doing experience. The integration was important to analyse the contribution of the model to the design process and to reveal the students' knowledge of mechanisms through final product designs. The study initially examines existing mechanics-based courses in main ID departments of Turkish Universities, followed by the research methodology to improve ID students' learning experience on mechanisms. Finally, results, conclusions and limitations of the study are presented with some implications.

Learning Styles in Design Education

Different studies on learning styles exists in the literature. Nevertheless, Kolb's Learning Style Inventory (K-LSI) is the most widely utilised model due to its generalised and reliable structure (Carmel-Gilfilen, 2012; Demirbas and Demirkan, 2003; Demirkan and Demirbas, 2008; Demirkan, 2016; Kayes, 2002; Kvan and Yunyan, 2005). Similarly, K-LSI model is employed widely in the different design disciplines (Carmel-Gilfilen, 2012; Demirbas and Demirkan, 2003, 2007; Demirkan and Demirbas, 2008; Kvan and Yunyan, 2005; Nussbaumer and Guerin, 2000; Tucker, 2007, 2009). According to Kolb's model, a learning cycle is composed of four stages; concrete experience (CE), reflective observation (RO), abstract conceptualisation (AC) and active experimentation (AE).

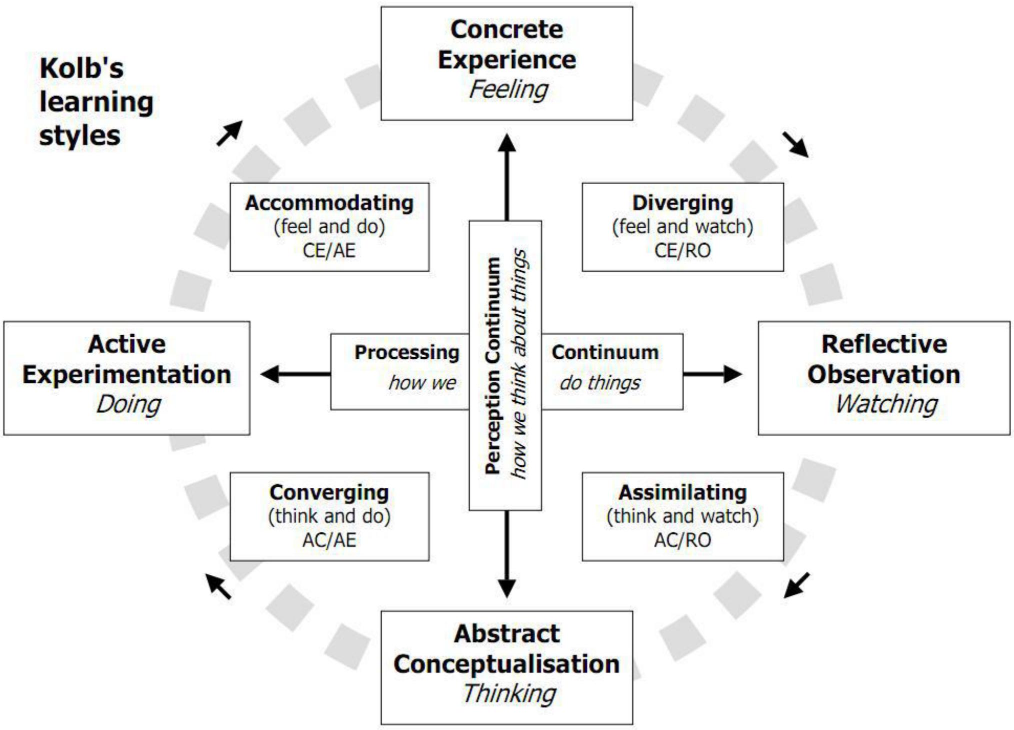


Figure 1. The four-staged learning cycle and the four learning styles (http://www.n-co.org/wp-content/uploads/2016/01/david-kolb-method1.jpg)

Based on these four stages (Figure 1), Kolb classified learners into one of four learning styles, namely converger (AC and AE), diverger (CE and RO), assimilator (AC and RO), and accommodator (CE and AE) (Kolb, 1984).

Studies on learning styles of design students indicated different results. Studies by Demirbas and Demirkan (2003, 2007), and Tucker (2007) determined that the most of design students were converger and assimilator. In contrast, studies by Kolb and Wolfe (1981), Nussbaumer and Guerin (2000), Bender (2004), and Carmel-Gilfilen (2012) determined that design students were mostly diverging and accommodating learners. Carmel-Gilfilen (2012) supports that although all learning styles are found in studies due to the multidisciplinary nature of design, diverging and accommodating learning styles are more appropriate for design majors. These learning styles match up with a studio-based learning style in design disciplines. Based on Kolb's learning styles (1984), divergers are good at brainstorming and idea generation, inclined to be imaginative and emotional. Accommodators show preference for doing and feeling. They like working in teams and experimental studies. The common point of these two learning styles is concrete experience (CE) or learning by experience. Carmel-Gilfilen' study supports that designers prefer experiencing the concrete and substantial qualities of the world to discover meaning.

Studies on learning styles of design students reveal that despite differences in ratio, all of the four learning styles exist in design education. Therefore, it is supported that instead of applying one of the four learning style, a diverse instruction covering all learning styles should be adapted to design education (Carmel-Gilfilen, 2012; Demirbas and Demirkan, 2003, 2007; Demirkan and Demirbas, 2008; Demirkan, 2016; Kvan and Yunyan, 2005). In addition, it is found that teaching including all learning styles in balance develops learning outcomes (Nussbaumer, 2001).

Demirkan (2016) investigated the learning-style (Sensing/Intuitive and Visual/Verbal) and knowledge-building (Active/Reflective and Sequential/Global) preferences of design students utilising Felder-Soloman's Index of Learning Styles. The study found that design students prefer a sensing learning style such as facts and concrete material rather than theories. The study also revealed that designers prefer visual information rather than verbal ones. It is unsurprising that designers learn better with pictures, schemas and videos. Moreover, it is found that design students are active learners; they prefer teamwork and hands-on activities, like sketching or constructing a 3D model. They learn better by doing and applying.

Design education needs a holistic approach that emphasises learning by doing and experiencing but allows students to learn by reflecting and thinking as well. It can be achieved by providing different type of assignments like two- and three-dimensional work, visual and verbal assignments, and individual or teamwork (Carmel-Gilfilen, 2012).

Teaching of Mechanisms in Industrial Design Education

Engineering-based courses in the main ID departments in Turkey are generally taught either by instructors from Mechanical Engineering Departments or by industrial design instructors with a professional background in engineering. Engineering-based courses in main ID departments of Turkish Universities are indicated in Table 1. As seen in Table 1, mechanics-based courses only exist in some universities' curricula. In Gazi University, the Mechanism and Details course was added to the curriculum in 2014-2015 academic year.

Engineering-based courses	Gazi Uni.	Middle East Technical Uni.	Istanbul Technical Uni.	Izmir University of Economics	Anadolu Uni.	Bahçeşehir Uni.	Marmara Uni.
Mechanics-based	Mechanisms and Details		Introduction to Mechanical Design			The Way Things Work	Design Construction
Manufacturing-based	Manufacture Methods	Principles of Production Engineering	Manufacture Methods	Production Technology	Manufacture Methods		Production Techniques
Material-based	Materials	Manufacturing Materials	Statics & Strength of Materials	Materials for Industrial Design	Material Science	Manufacture Materials	Material Technology

Table 1. Engineering-based courses in ID departments

Through the learning outcomes indicated in Table 2, it is seen that the courses in Gazi University and Istanbul Technical University cover mechanisms and mechanical design issues in detail, whereas the other two courses (The Way Things Work and Design Construction) are included partially.

The courses summarised above are generally lecture-based with a high degree of abstraction. As seen in Table 2, the outcomes of these courses are generally evaluated through quizzes, midterm and final examinations and homework assignments. Therefore, students do not have the opportunity to transfer theoretical knowledge into practical achievements throughout the course period.

In contemporary design education, the courses are divided into four categories: 1) fundamental courses 2) technology-based courses 3) artistic courses 4) design studio courses (Demirbas and Demirkan, 2007; Demirbas, 2001; Uluoğlu, 1990). The second category, technology-based courses, consists of the courses that are theoretical based but directly related to practice named as construction, structure, material etc. (Uluoğlu, 1990). Accordingly, engineering-based courses belong to the second category. This implies that students' acquired knowledge in mechanics-based courses should be not only theoretical but also practice-based. It is widely accepted that a theoretical teaching style alone is insufficient to equip design students with the skills required during professional life (Hook, Hjermitslev, Iversen & Olivier, 2013). Design educators look for teaching models that form the combination of theories, techniques, and skills to reflect the students' individual approaches (Demirbas and Demirkan, 2007; Schön, 1987). Therefore, it is essential to combine theoretical knowledge with real-world practical experience for design students.

	Gazi Uni.	Istanbul Technical Uni.	Bahçeşehir Uni.	Marmara Uni.
Course Names	*Mechanism and Details*	*Introduction to Mechanical Design*	*The Way Things Work*	*Design Construction*
Learning outcomes	*1. Understand the basic mechanisms components* *2. Understand and interpret the mechanisms and connection types* *3. Have full knowledge of exploded view and detail display through mechanisms* *4. Understand the place and contribution the solution of electronic circuits in mechanisms* *5. Develop mechanism based problem solving*	*1. Understand the fundamentals of mechanical systems* *2. Understand the physical principles of mechanical systems* *3. Understand the basic elements used in mechanical systems* *4. Develop the basic skills for analysing existing mechanisms* *5. Develop the skills to find mechanical solutions during designing*	*1. To identify assembling and disassembling procedures of objects in order* *2. To explain the circular movement, linear movement and ex-centric movement* *3. To differentiate the elements of simple mechanics* *4. To apply the principles of simple mechanics to the new design of objects* *5. To compare various power sources* *6. To support the mechanics and working principles of objects with the renewable energy sources*	*1. To evaluate design from a different perspective* *2. To examine about design development process and development of its applications* *3. To identify both design and engineering contexts about statics, dynamics and mechanics* *4. To analyse the basic principles of physics in the context of industrial design* *5. To explain the relationship between design and construction*
Assessment Criteria	*Midterm exam Final exam*	*Homework Assignments* *Quizzes* *Midterm project* *Final project*	*Homework Assignments* *Quizzes* *Midterm exam* *Final exam*	*Homework Assignments* *Midterm exam* *Final exam*

Table 2. Summary of the courses

In design education, design studio courses are the most crucial part and they are the synthesis of all other courses (Demirbas and Demirkan, 2007). The aim of courses other than design studio courses is to provide students with theoretical and practical knowledge that they can utilise in design studio projects. However, it is seen that there is no concrete bridge between the design studio courses and mechanics-based courses. Although students gain sufficient theoretical and practical knowledge of mechanisms, they have difficulties in applying this knowledge to a real design project. Thus, there is a need for a new teaching model of mechanism for ID students combining theoretical and practical knowledge with an applied learning style.

Design of New Teaching Model of Mechanisms

Methodology

The implementation was conducted at Gazi University, the department of Industrial Product Design within second-year ‘Product Design II’ course. The aim of this application was to improve ID students’ learning experience on mechanisms by utilising an applied learning style and to enable them to transfer their knowledge of mechanisms into the design project.

In consequence of the above discussions, a new teaching model of mechanisms that combines different styles but mainly based on an applied learning style covering two stages of Kolb’s learning cycle: active experimentation (learning by doing) and concrete experience (learning by experiencing) was designed. This teaching model was integrated to design project and conducted thoroughly within product design-studio course.

The new teaching model consists of three main phases: Improving theoretical knowledge of mechanisms and possible applications, in-depth practical knowledge of specific mechanisms and application of mechanism into the design process (Figure 2).

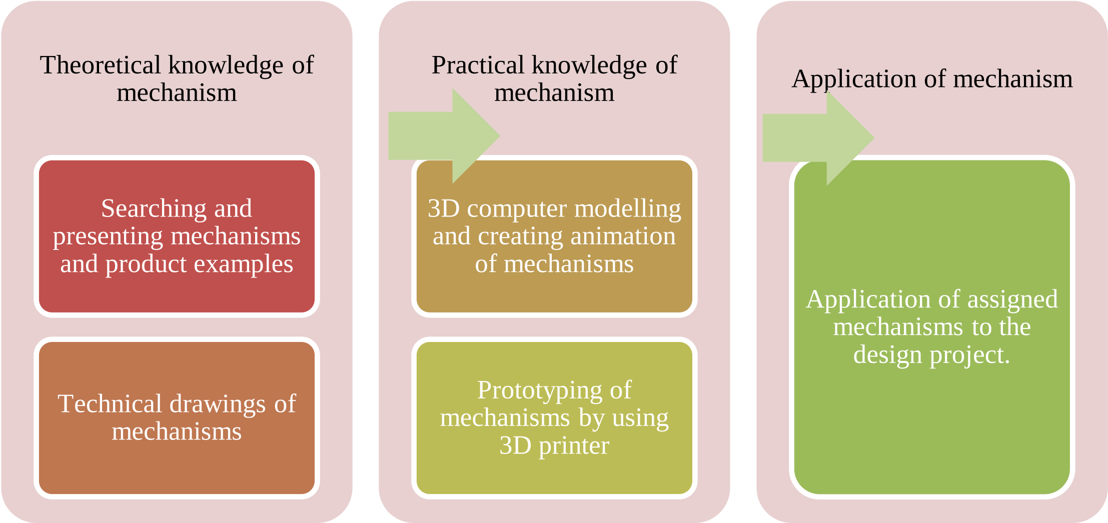


Figure 2. Phases of new teaching model of mechanisms

Improving theoretical knowledge of mechanism and possible applications.

This phase consists of searching and presenting a working system of mechanisms and mechanism-based product examples including the technical drawings and related 3D animations. The teaching method specified a series of reference materials for students' self-study to improve and revise their knowledge obtained in previous courses. Concrete outcome oriented presentations were requested and apart from the recommended self-study materials, students are allowed to show all related information about assigned mechanisms for reinforcing their knowledge through drawing different perspectives. Some amount of the mathematical content was removed except for two sections related to planar linkage degrees of freedom and transmission system speed ratios that are essential for the holistic approach of the final product. Mechanical applications in industrial design are mainly concentrated on the motion mechanisms. Therefore, most of the assigned mechanisms classified based on their level of complexity were focused on planar mechanisms and transmission systems. The functions of the planar mechanisms were requested to be solved in terms of their operative systems such as copying, changing direction, scaling and other basic operations. Students abstracted general principles of the assigned mechanisms around their environment in order to build mechanical knowledge through their initiative in studying everyday objects. Afterwards, the students are guided toward drawing conclusions on theoretical knowledge through practical life conditions. During the studio criticisms, combined applications in problem-solving are carried out to give students experience in analysing situations while, at the same time, seeking solutions to problems through theoretical principles.

Within this process, their skills in applying knowledge were strengthened and their analysis was encouraged with additional 3D animations and video presentation of typical mechanical products as well as necessary detailed technical drawings including perspectives, different views, and sectional views.

In-depth practical knowledge of specific mechanisms

This phase consists of 3D computer modelling and animation of the assigned mechanisms and creating the prototype of the mechanisms by using the 3D printer. The ultimate goal for industrial design students, who study courses on mechanical design, is to increase their advantage in product design and to eliminate the biased common impression that industrial design is just styling (Liu and Wu, 2013). The authors' department was equipped with 3D printers, allowing students to turn their modelled mechanisms into concrete models, which greatly enhances also their knowledge of modelling obtained in computer aided design courses. In this stage, students actively learn mechanisms by doing and experiencing. In case of false scaling, the students re-model the assigned mechanism until it matches with the appropriate output from the 3D printer. They test and improve the design of the mechanism by modifying the scales, features and mechanical functions of the virtual models by adjusting the parameters. Thus, the modelling and testing capabilities of the students were increased in terms of developing a full understanding of their own mechanisms, both theoretically and perceptually.

Application of mechanism into a design process (action learning)

In this phase, students apply the mechanisms in a specific real design project. Students are requested to develop a product including their assigned mechanism after the completion of phase 1 and appropriate modelling in phase 2. Thus, the better comprehension of creating a functional prototype through the active application of the assigned mechanism was the main learning outcome of this final phase. In some drafts of the integrated design cases, the training and implementation were even carried out on combined applications of more than one mechanism.

According to the above-mentioned phases of the proposed teaching model, design brief and assignments were formed as indicated in Section 3.

The Project Brief: Mechanical Game Design

To apply the new teaching model of mechanisms to the design-studio project, many product ideas were discussed while preparing the design brief in terms of their suitability to assigned mechanisms, complexity, and approximate duration. Since the main purpose of the project was to provide students to gain practical knowledge of mechanisms, the mechanism should not have played a recessive role in the product. Therefore, it was decided to constitute a project brief for a mechanical game design. It was thought that a mechanical game design project allowed more alternatives for the students in terms of both creativity of the final product and appropriate application of mechanisms.

The anticipated steps while preparing design brief and assignments are as follows:

Specifying mechanisms

Mechanisms assigned to the students were judged according to their suitability to the mechanical game design project. As product designers generally utilise movement mechanisms in their products (Liu et al., 2013), this type of mechanism was chosen to assign to the students. These mechanisms were distinguished into three categories in terms of their relative complexity (Table 3).

	Less complex	*Complex*	*More Complex*
1	*Worm Wheel*	*Crankshaft-Rod*	*Cardan Gear*
2	*Sprocket Wheel*	*Bellcrank*	*Universal Joint*
3	*Belt-pulley*	*Camshaft*	*Geneva Drive*
4	*Bar-Pendulum Linkage*	*Drop/Snail Camshaft*	*Internal Geneva Drive*
5	*Double Pendulum*	*Scotchyoke*	*Planet Gear*
6	*Hoekens Linkage*	*Ratchet Wheel*	*Looney Gear*
7	*Ball Joint*	*Scissors Mechanism*	*Chuck*
8	*Gear Train*	*Scissors Jackscrew*	*Iris Diaphragm*
9	*Elliptical gear*	*Bevel Gear*	*Variable Speed Gears*
10	*Torsion Spring*	*Helical Gear*	*Anchor Escapement*
11	*Archimedes' Screw*	*Tusi-Couple*	*Ferguson's Paradox*
12		*Centrifugal Governor*	*Withworth Mechanism*
13			*Barrel/Cylindrical Cam*

Table 3. Three categories of movement mechanisms

Forming teams

A total of 41 industrial design sophomores attending a 'Product Design II' course participated in the project. The demographic makeup included 34 females and 7 males. Students were formed into teams consisting of three members.

Assigning mechanisms

All teams chose one mechanism from each of three mechanism categories. All the members of each team were responsible for the detailed analysis of three mechanisms that they chose for the first phase of the training process.

Phase 1: Improving theoretical knowledge of mechanisms and possible applications

Assignment 1: Teams were asked to search mechanisms assigned to them (three mechanisms ranging from less complex to more complex). Searching included materials describing the principles of mechanisms via both visual (technical drawings, renders of 3D computer models and pictures) and video-based approaches as the details are mentioned in the section of methodology. In addition, to gain concrete knowledge about mechanisms, the products or systems around their environment that these mechanisms are utilized were also searched. Teams were also asked to make a technical drawing of all three mechanisms. They submitted and presented all assignments to the instructors. At the end of this phase, three mechanisms assigned to the teams were reduced to two for further in-depth analysis and 3D modelling based on their exhibited competencies and their interest in the mechanisms through the samples of real life conditions indicating that interest is the main motivator in stimulating students' passion for learning and research.

Phase 2: In-depth practical knowledge of specific mechanisms

Assignment 2: Basing on the selection of two mechanisms per team, the students started in-depth analysis on the mechanism systems. Each team created 3D models of these mechanisms by using Autodesk Fusion 360. Teams also set up a motion study in Fusion 360 to analyse their operative systems and movements (rotations, translation, transmission, changing directions etc.) of the parts of mechanism and tested whether it worked appropriately or not. The methodology of the process was fulfilled as mentioned in the previous section.

After the presentations of the 3D models and motion studies of the two mechanisms of each team, the instructors, based on the interest, motivation and previous studies of the students for providing a gap with their environment, chose and assigned one mechanism to each team (Table 4) for the further 3D printing process.

Teams	*Mechanisms*
Team 1	*Centrifugal Governor*
Team 2	*Drop/Snail Camshaft*
Team 3	*Scotchyoke*
Team 4	*Worm Wheel*
Team 5	*Crankshaft-Rod*
Team 6	*Universal joint*
Team 7	*Archimedes' Screw*
Team 8	*Planet Gear*
Team 9	*Ferguson's Paradox*
Team 10	*Iris Diaphragm*
Team 11	*Camshaft*
Team 12	*Geneva Drive*
Team 13	*Cylindrical Cam*
Team 14	*Withworth Mechanism*

Table 4. Mechanisms assigned to teams

Assignment 3: 3D models created in Fusion 360 were examined by instructors to make them ready for 3D printing. The thickness of the parts, tolerances between the parts and overall scales of the models were optimised according to existing 3D printer features. All prototypes of mechanisms were created by using Zortrax M200 within the GAZİ D-LAB (Digital Design Laboratory of Gazi University).

Phase 3: Application of mechanism into a design project (action learning)

Mechanical Game Design: After assigning the mechanisms that each team was responsible for, the process for designing a game based on the assigned mechanism was initialised. This process is also called "action learning" and the project subject was chosen in order to minimise the possible negative pressure and impacts on the students' creative thinking.

The main specifications for the mechanical game design were as follows:

- Teams have to apply the mechanism assigned to them at least once in the active systems of their designs. In a case of more complex system designs, they can add additional mechanisms where required.
- The product should be manually operated or powered.
- There is no limitation on material usage and scale of the product.
- The product can be designed for different age groups.

Working in teams of three students, each team had a total of 5 weeks (Total 40 hours of active studio hours and approximately 70 hours of work outside studio hours including research, case studies, and practices) to finalise the product design. Within the first 4 weeks, teams developed design ideas and formed them as design proposals through studio critiques. They presented their two design proposals including research report, technical and perspective drawings and 1/1 physical mock-ups in the preliminary jury. Instructors chose one of two proposals for teams to continue to improve until the final jury. Each team finalised and presented their mechanical game designs at the end of fifth week.

Project management

To manage the project lifecycle the students' submissions and timing were important. The sequence of the submissions was arranged parallel with the project brief. The duration of each submission was developed by regarding the students' previous project performances. All submissions and timing of the stages are demonstrated in Table 5.

Project Phases	*Week*	*Submissions*
	1	*Team member selection*
Improving theoretical knowledge of mechanisms and possible applications		*Assignment 1* *-Research report on 3 mechanisms* *-Presentation of detailed technical drawings of mechanisms* *-Selection of 2 mechanisms per each team for further phase*
In-depth practical knowledge of specific mechanisms	*2*	*Assignment 2* *-3D modelling of two mechanisms in Fusion 360* *-Motion study of two mechanisms in Fusion 360* *-Selection of one mechanisms per each team for 3D prototyping*
	3	*Assignment 3* *-3D printed prototypes of the selected mechanisms*
Application of mechanism into a design project (action learning) *Mechanical Game Design*	*4*	*Preliminary Jury* *-Presentation of research, technical and perspective drawings* *-1/1 physical mock-ups*
	5	*Final Jury* *-Presentation of research, technical and perspective drawings* *-1/1 physical model*

Table 5. Submissions and timing

Evaluation of the New Combined Model

To be able to evaluate the teaching model effectively, the project was conducted during the second semester of the 2016/2017 academic year since the participating students taking Product Design II course had studied the Mechanisms and Detail course in the previous semester. Therefore, it was anticipated that they would appropriately evaluate their learning outcomes and compare their practical improvements and competencies with respect to the gained knowledge and skills in the previous related courses. To evaluate the proposed new teaching model, two data acquisition techniques were utilised:

- Process observations and analysis of the submissions
- Post-project questionnaire

Process observations and analysis of the submissions

During twice a week studio critiques (10 hours per week), teams received evaluative feedback for their design ideas. Feedback was beneficial for both learning and application of mechanisms in the design process. Studio critiques were important to record the attendance and the progress of each team and to analyse the appropriateness of the proposed teaching model.

The process observations and analysis of the submissions were conducted each week after 10 hours of studio critiques basing on the expected learning outcomes and competencies for each phase foreseen by the project instructor team while creating the methodology. As mentioned before, the proposed new teaching model of mechanisms combined different learning styles but was mainly based on an applied learning style covering two stages of Kolb's learning cycle: active experimentation (learning by doing) and concrete experience (learning by experiencing). In addition to these aspects, the professional competencies that Liu et al. (2013) suggested (aesthetic literacy, design expression, creativity, planning and integration capability, engineering capability, computer application skills and ergonomics knowledge) skills were considered through different rates while determining the process based on the nature of the established methodology.

Consequently, the structure of the expected learning outcomes and competencies in each of the three phases of the methodology that are the base of the process observations and submission analysis, were determined as follows:

Phase 1: Improving theoretical knowledge of mechanisms and possible applications:

- Research, analyse and synthesise knowledge about specific mechanisms for the development of a design response (engineering capability, design expression)
- Understand the fundamental concepts of the given mechanisms through technical drawings including perspectives, different views and sectional views (engineering capability)
- In-depth analysis and 3D modelling (engineering capability, computer application skills, planning and integration skills)
- Understanding the role of the assigned mechanisms through the samples of real life conditions (design expression, aesthetic literacy)

Phase 2: In-depth practical knowledge of specific mechanisms:

- Active learning of the assigned mechanism by doing and experiencing (computer application skills, engineering capability, planning and integration capability)
- Test and improve the design of the mechanism by modifying the scales, features and mechanical functions of the virtual models by adjusting the parameters (computer application skills, creativity)
- Appropriate modelling and obtaining output from 3D printer / understanding the mechanism perceptually (planning and integration capability, engineering capability, computer application skills, design expression)

Phase 3: Application of mechanism into a design process (action learning):

- Apply fundamental design principles (primary elements, composition of form, proportion and scale) to their work (aesthetic literacy, design expression, creativity)
- Explore creative processes and idea generation and demonstrate critical evaluation of these processes in the assessable work (aesthetic literacy, design expression, planning and integration capability, creativity, engineering capability, ergonomics knowledge)
- Communicate critical design thinking according to disciplinary conventions, drawings, models, mock-ups and other presentations (design expression, aesthetic literacy, planning and integration capability)
- Work productively in a studio environment and, in turn, develop inter-personal skills, verbal communication skills and critical thinking through small group activities and studio exercises (planning and integration capability, creativity, design expression)

Post-project questionnaire

The post-project questionnaire was administered following the final assignment. 37 participants completed the questionnaire during the final day of the project. To get evaluative feedback about the effectiveness of the new teaching model, a 4-part questionnaire was developed using a Likert scale. In the first part of the questionnaire, the impact of the project phases (research, technical drawings, 3D computer modelling, animating, 3D printing, creating concept ideas, and application of mechanism in product) on learning mechanisms were rated, with 1 corresponding to “minimum” and 5 corresponding to “maximum”. In the second part, participants were asked to explain which phase of the project was the most challenging. In the third part, participants were asked to rate their level of knowledge on Autodesk Fusion 360 and 3D printing for before and after the project. In the final part, participants were instructed to rate the acceptability of the given sentences on a Likert scale of 1 to 5, with 1 corresponding to "strongly disagree" and 5 corresponding to "strongly agree". Basic statistical values were calculated for all parts of the questionnaire. In addition to that, in part 3 paired sample t-test was applied in order to observe the improvements in Autodesk Fusion 360 and 3D printing before and after the use of the teaching methodology.

Results

41 industrial design students attending ‘Product Design II’ course participated in the mechanical game design project, resulting in 14 student teams. All teams finalised the mechanical game design project to different levels of different aspects. The results were gained from two data capture techniques: project observations gathered by instructors throughout the process and the post-questionnaire conducted with participating students at the end of the project.

Results of the process observations

To analyse the appropriateness of the phases of the project separately, the project is discussed for each phase through the process and the submissions.

Phase 1: Improving theoretical knowledge of mechanisms and possible applications

As mentioned before, in this phase, teams were asked to search mechanisms and make technical drawings of these mechanisms (3 mechanisms ranging from less complex to more complex) assigned to them. The aim was to gather information about mechanisms and how these mechanisms are utilized in products. While some teams' research was limited to the proposed reference materials and internet search, some started to work with physical mechanisms. Physical mechanisms allowed teams to comprehend motion of the mechanisms more easily. The majority of research presentations were limited to only google images and texts. Through detailed technical drawings, it was aimed to enable students to learn the parts composing the mechanisms and comprehend the motion and transmission system. It was observed that teams with insufficient research had trouble while making technical drawings especially in dimensioning and scaling of the parts of the mechanisms. Although these applications were not sufficient for fully understanding motions of the mechanisms, students had improved their general knowledge of mechanisms at the end of this phase. After appropriate guidance, most of the students were able to abstract general principles of the assigned mechanisms around their environment and tried to provide a gap between the mechanism and practical life conditions. Approximately, half of the student groups even tried to analyse situations that need combined applications that require at least two or more mechanisms in a relatively complex system.

Phase 2: In-depth practical knowledge of specific mechanisms

As mentioned before, teams were assigned to create 3D models and animation of their mechanisms by using Autodesk Fusion 360 in this phase. Teams struggling while dimensioning the related parts of the mechanisms also had trouble while 3D modelling in Autodesk Fusion 360. Deciding wall thicknesses, tolerances between the parts and calculating gear ratios were some of the challenges teams faced. With instructors' directions, each team revised their Fusion models. The most challenging stage for teams was animating of the mechanisms as they had not sufficient knowledge on making animation in Fusion 360. Despite these difficulties, nearly all teams succeeded in making an animation of their mechanisms at the end. Some examples of teams' 3D models created by Autodesk Fusion 360 are demonstrated in Figure 3.

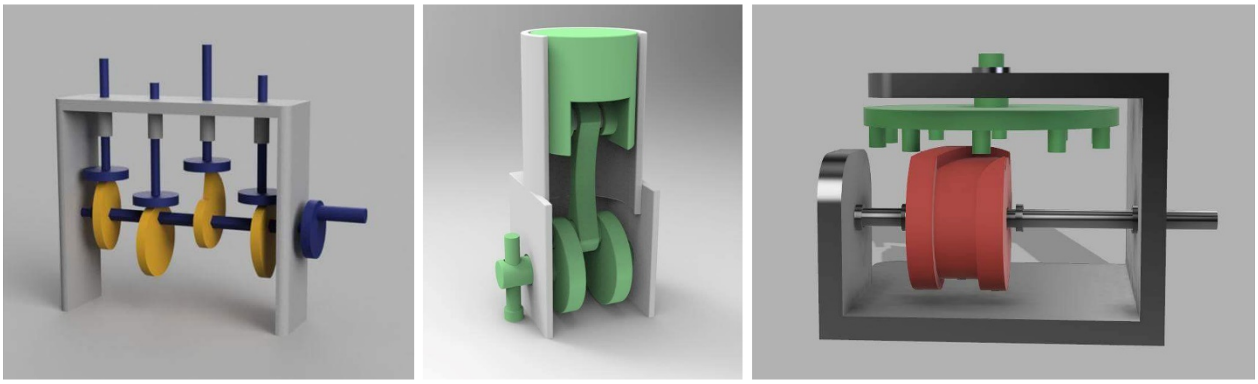


Figure 3. Examples of teams' 3D models created by Autodesk Fusion 360

Following 3D modelling, again with the support of instructors, models were optimised for 3D printing. Wall thicknesses and tolerances of the models were revised according to the features of the 3D printer. In spite of all these optimisations, some errors occurred while 3D printing. Some parts of the models could not fit together due to insufficient tolerances. In addition, low wall thicknesses of some parts resulted in breaking these parts. However, these problems encountered during 3D printing allowed students to concretely see their mistakes made during 3D modelling. All teams' final 3D printed mechanism models are demonstrated in Figure 4.

In this phase, the aim was to apply knowledge acquired during phase 1 and 2 to the design process and action learning. Each team created mechanical game design ideas depending on mechanisms assigned to them. All students engaged in the process using design techniques by making sketches and mock-ups. It was observed that although students were generally motivated by the project, they found the process challenging. Student comments revealed that most of them comprehended the principles of the mechanisms but had difficulties to apply the mechanisms to the product design. They thought that by being limited with a specific mechanism also limited them in creating product ideas. In fact, this limitation enabled them to focus on a specific function and created a starting point for them. During the initial phase, the most common mistake was inappropriate application of mechanisms to the design. They struggled to create product ideas relevant to their mechanisms. During studio critiques, some of their design alternatives were eliminated and they were directed to develop appropriate concepts. This helped remove their uncertainty and focus. Physical models developed in this process also allowed students to evaluate their design decisions. Eventually, students understood the importance the transferring theoretical knowledge to practice and apply this in a relevant way to a real product design process. Working in a team helped them to learn to share a responsibility and develop a working discipline. These all were significant outcomes that were expected from this new teaching model. Despite the difficulties of the process, all teams succeed in finalising their product designs and fulfilling all the requirements.

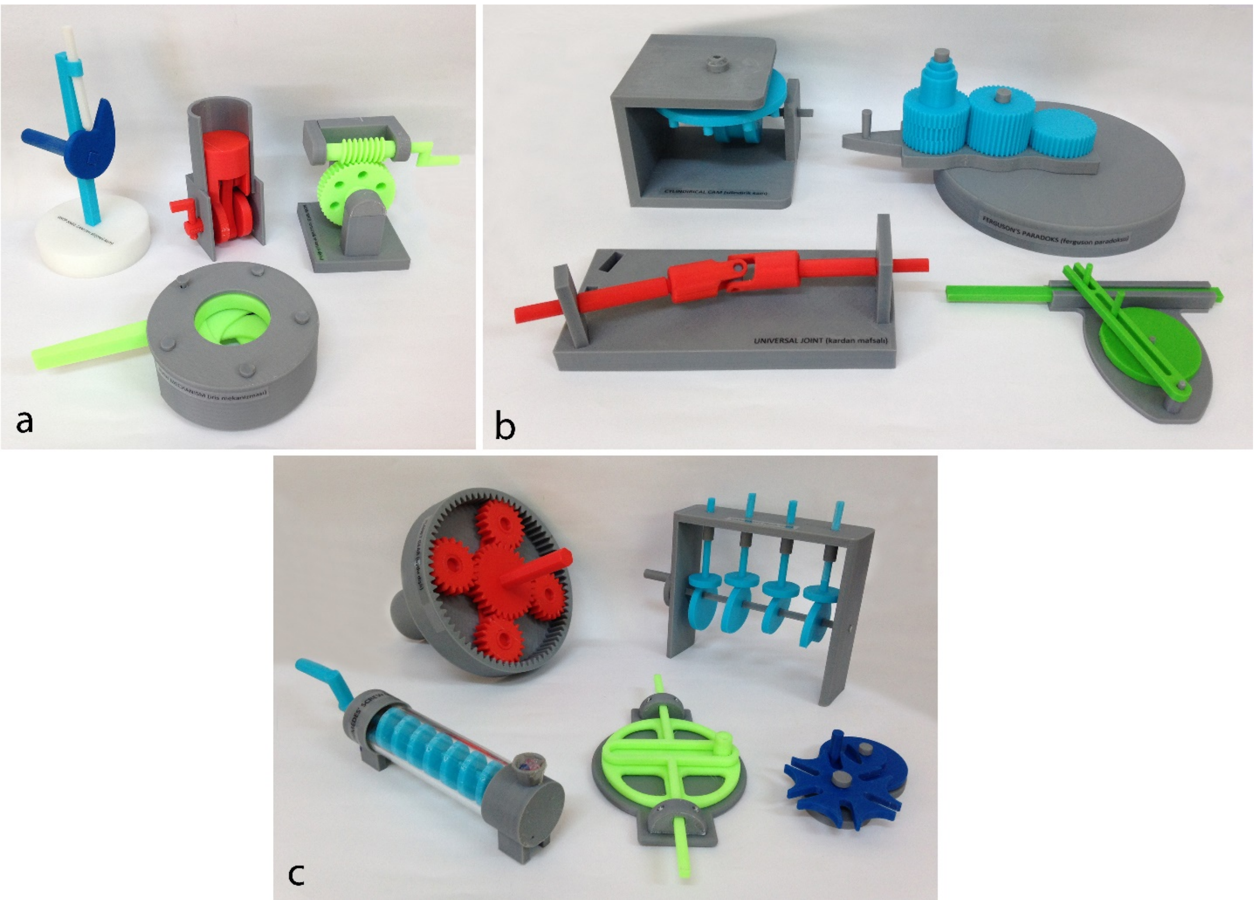


Figure 4. Teams' final 3D printed mechanism models a) Drop Camshaft, Crankshaft-Rod, Worm Wheel, Iris Diaphragm b) Cylindrical Cam, Ferguson's Paradox, Universal Joint, Withworth Mechanism c) Planet Gear, Camshaft, Archimedes' Screw, Scotchyoke, Geneva Drive

Phase 3: Application of mechanism into a design project (action learning)

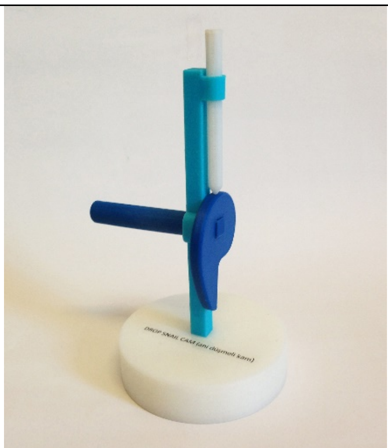
Some of the final products of the teams are shown in Figure 5 and summarised as follows:

Team 2- The Earthquake

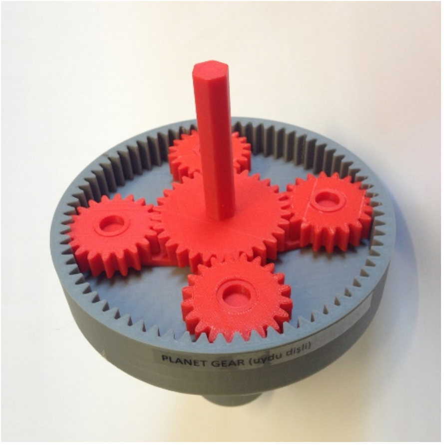
this is a board game utilising a drop camshaft mechanism. It can be played with two or in teams. The aim of the game is to create an arrangement on the card drawn by the competitor with the blocks within a certain period of time. The player selects a card from the decks and opens the card as soon as the timer attached to the platform is set. He tries to align the blocks as in the card. When the time is up, the platform suddenly falls and knocks over the blocks. If the game is completed correctly in time, the player gets the point written on the card.

Team 8- Complete the shape

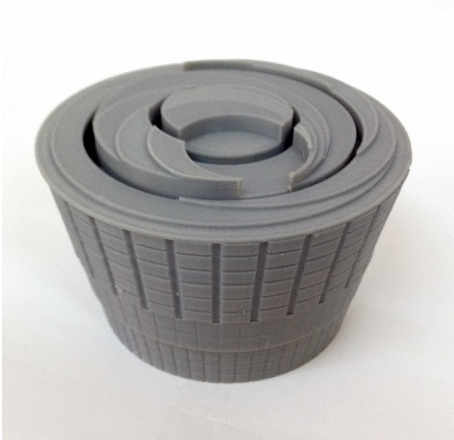
This one-player game is based on a planetary gear mechanism consisting of one environment, one sun, and three pinion gears. With the principle of the planetary gear mechanism, the two bearings always rotate together, depending on the rotating bearings. The goal of this game to complete the shape by rotating the disks attached to the gears.

	3D printed mechanism models	***Final Products***
Team 2	 Drop Camshaft	 The Earthquake

Team 8

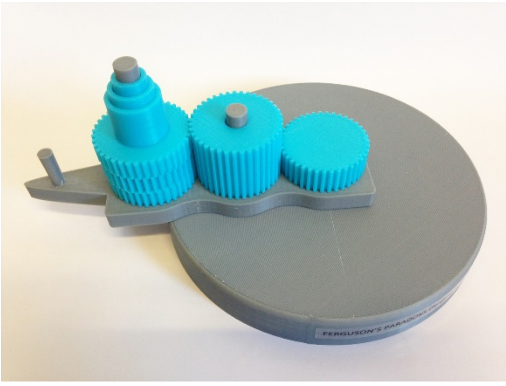


Planet Gear

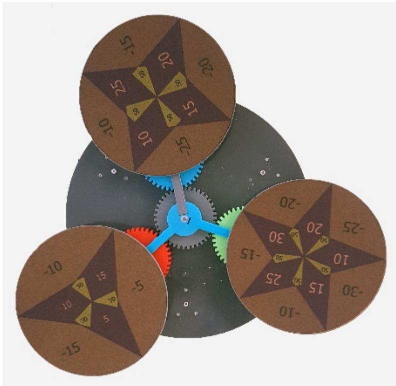


Complete the shape

Team 9

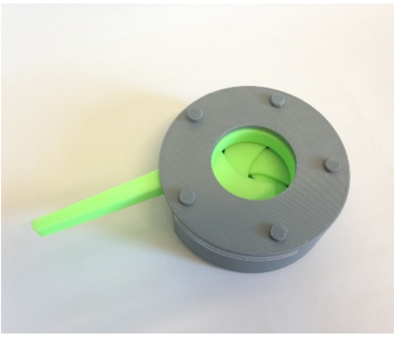


Ferguson's Paradox

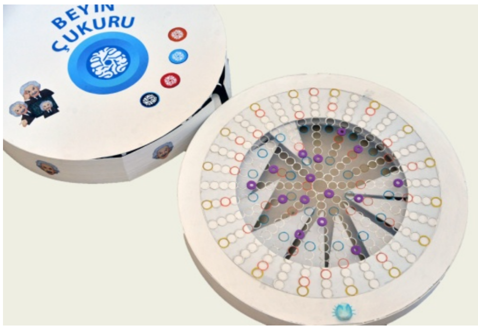


The Paradox Dart Board

Team 10

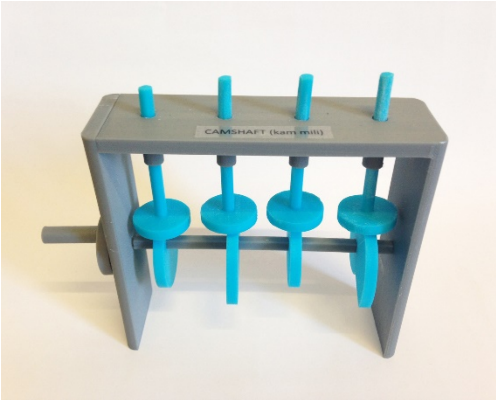


Iris Diaphragm



The Brain Pit

Team 11



Camshaft

The Climbing Game

Figure 5. Some of final products of the teams together with their mechanism models

Team 9- The Paradox Dart Board

Differently from dart board game, this has three rotating boards, which makes it more challenging. Ferguson's Paradox mechanism allows rotating boards in different speeds and directions. It can be played with two or in teams. The game consists of two parts. In the first part, the players try to shoot in positive areas to get points. In the second part, the players try to shoot in negative areas to reduce the score of the opposing players. The players with the highest score win the game.

Team 10- The Brain Pit

This game contains a perforated board and an iris diaphragm mechanism under it. Each player selects a pawn to start the game from the outer of the board. The player who cannot answer the question in the cards correctly move his pion one-step further. At the end of each tour, the iris diaphragm opens which means the nearest the player to the centre, has the highest risk to fall in the brain pit. The last player not falling in the pit wins the game.

Team 11- The Climbing Game

This game has a two-sided platform, which consists of stairs. The stairs attached to the camshaft can raise and lower pressing the button. The players try to get the balls to the top of the platform by raising and lowering the stairs. The balls reaching the top are added to the opposing player's ball pool. The player who finishes the balls first wins the game.

Post-project questionnaire results

From 41 students participated in the project, 37 completed the questionnaire. The 4-part questionnaire results are as follows.

Part 1: In this part, students rated the impact of project phases (research, technical drawing, 3D computer modelling, animating, 3D printing, creating concept ideas, and application of mechanism to design project) on the learning outcomes regarding mechanisms.

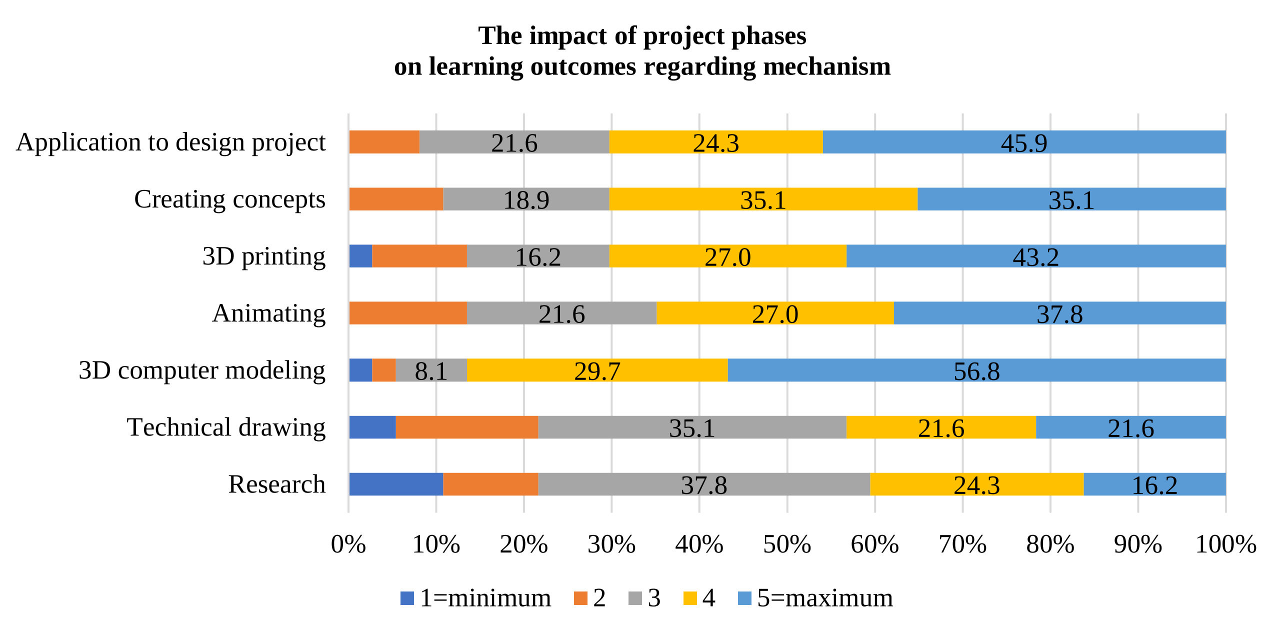


Figure 6. Results of post-project questionnaire part 1

As seen in Figure 6, "3D computer modelling" and "Application to design project (action learning)" received the most 5=maximum responses with 56.8% and 45.9% respectively. The impact of "3D printing" evaluated as 5=maximum with 43'2%. The mean of the all the responses to "3D computer modelling" was 4.35 (highest in the data set) with a standard deviation of 0.949. "Technical drawing" and "research" received the lowest 5=maximum response with 21.6% and 16.2% respectively (Table 6).

	Total (n)	*1 (%)*	*2 (%)*	*3 (%)*	*4 (%)*	*5 (%)*	*Total (%)*	*Mean*	*SD*
Research	*37*	*10.8*	*10.8*	*37.8*	*24.3*	*16.2*	*100*	*3.24*	*1.188*
Technical drawing	*37*	*5,4*	*16.2*	*35.1*	*21.6*	*21.6*	*100*	*3.37*	*1.163*
3D computer modelling	*37*	*2.7*	*2.7*	*8.1*	*29.7*	*56.8*	*100*	*4.35*	*0.949*
Animating	*37*	*0*	*13.5*	*21.6*	*27.0*	*37.8*	*100*	*3.89*	*1.075*
3D printing	*37*	*2.7*	*10.8*	*16.2*	*27.0*	*43.2*	*100*	*3.97*	*1.142*

Creating concepts	*37*	*0*	*10.8*	*18.9*	*35.1*	*35.1*	*100*	*3.94*	*0.998*
Application to design project	*37*	*0*	*8.1*	*21.6*	*24.3*	*45.9*	*100*	*4.08*	*1.010*

Table 6. Basic statistics of the results of post-project questionnaire part 1

Part 2: In this part, the students were asked which were the most challenging phase of the project together with their reasons. The results of responses to the most challenging phase of the project were demonstrated in Figure 7. As seen in the pie chart, the most frequently occurring response was "application of mechanism to design project (action learning)" with 64,9%. "Research" and "technical drawing" received the lowest rating with 2,7%.

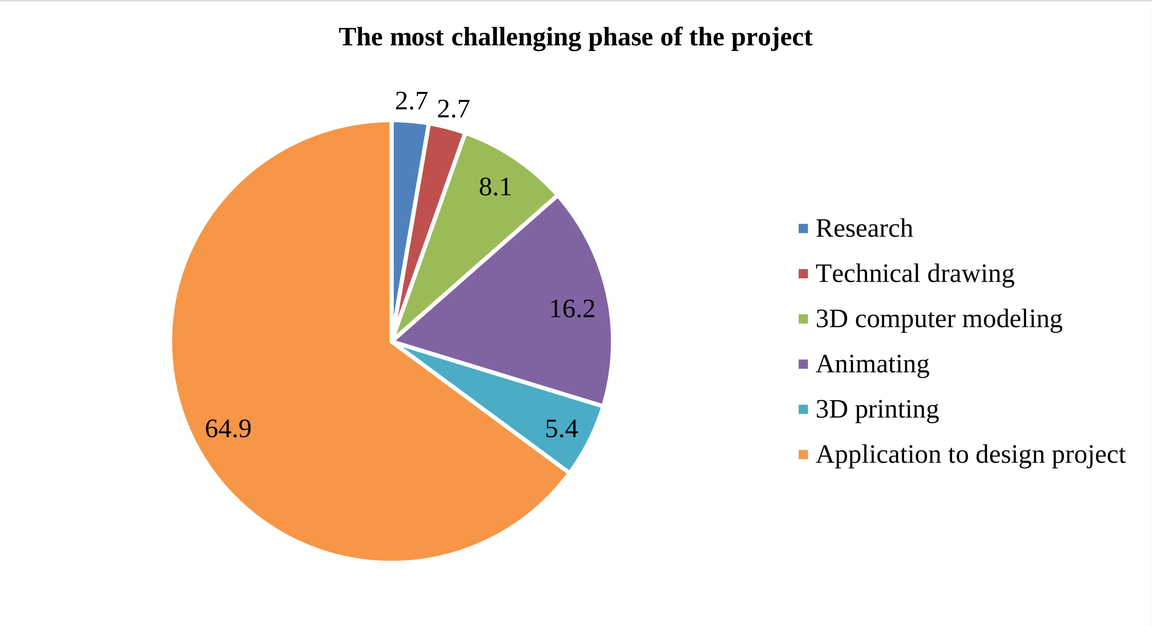


Figure 7. Results of post-project questionnaire part 2

The reasons given by the students who marked "application of mechanism to design project (action learning)" as the most challenging phase of the project are summarised as follows:

- It was challenging that we have to apply assigned mechanism to design project.
- Due to the complexity of the mechanisms, it was difficult to apply the mechanisms to the design project and this made the process more exciting and ambitious.
- We had to create too many design concepts to apply the mechanism appropriately; therefore, it made the process difficult and more intensive.
- Creating the form of a mechanical game design depending on an assigned specific mechanism was difficult thus we had to implement all motional characteristics of the mechanism through various drafts in order to provide a creative game design.
- Teamwork led to contradictory and challenging design ideas.

- Explanations of the students who provided “animating” as the most challenging phase of the project are summarised as follows:
- Since I have not enough knowledge and skills on animating, it was challenging to create motions of mechanisms leading to specific competencies.
- I had trouble while animating motions of mechanism on Autodesk Fusion 360
- Part 3: In the third part, students rated their level of knowledge on Autodesk Fusion 360 and 3D printing for before and after the project.

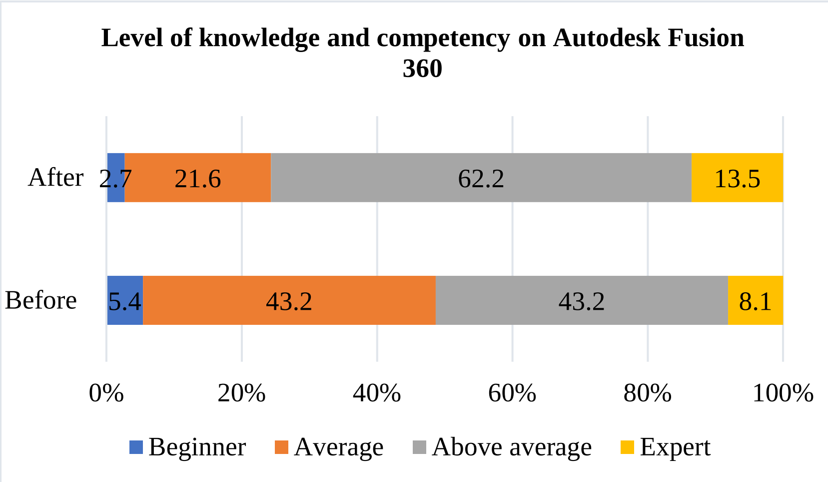


Figure 8. Results of post-project questionnaire part 3 about the level of knowledge and competency on Autodesk Fusion 360

As seen in Figure 8, before the project, knowledge of students on Autodesk Fusion 360 was centred upon average and above average level. After the project, the majority reached the above average level (62.2%). A paired-samples t-test was conducted to compare the level of knowledge on Autodesk Fusion 360 before and after the project. There was a significant difference in the responses for before (M=2.5405, SD=0.730091) and after (M=2.864865, SD=0.673390) situations, p = .000 (Table 7).

	Total (n)	*Beginner (%)*	*Average (%)*	*Above average (%)*	*Expert (%)*	*Total (%)*	*Mean*	*SD*	*Sig. (2-tailed)*
Before	*37*	*5.4*	*43.2*	*43.2*	*8.1*	*100*	*2.5405*	*0.730091*	*.000*
After	*37*	*2.7*	*21.6*	*62.2*	*13.5*	*100*	*2.864865*	*0.673390*	

Table 7. Results of paired-samples t-test of post-project questionnaire part 3 (level of knowledge and competency on Autodesk Fusion 360)

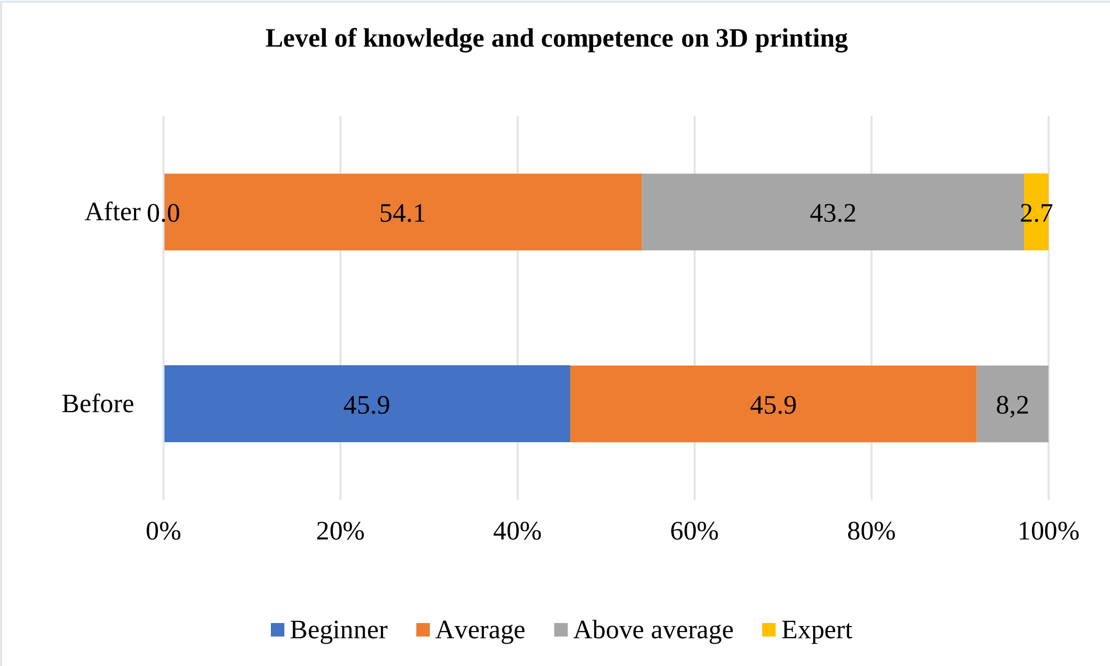


Figure 9. Results of post-project questionnaire part 3 about the level of knowledge and competency on 3D printing

As seen in Figure 9, before the project, knowledge of students on 3D printing was centred upon beginner and average level. After the project, the centre shifted towards average and above average level with 54,1% and 43,2% respectively. A paired-samples t-test was conducted to compare the level of knowledge on 3D printing before and after the project. There was a significant difference in the responses for before (M=1,6216, SD=0,63907) and after (M=2,4865, SD=0,55885) situations; p = ,000 (Table 8).

	Total (n)	Beginner (%)	Average (%)	Above average (%)	Expert (%)	Total (%)	Mean	SD	Sig. (2-tailed)
Before	37	45.9	45.9	8.1	0	100	1.6216	.63907	.000
After	37	0	54.1	43.2	2.7	100	2.4865	.55885	

Table 8. Results of post-project questionnaire part three (level of knowledge and competency on 3D printing)

Part 4: In this part, students rated the acceptability of the 10 questions related to the project process on a Likert scale of 1 to 5, with 1 corresponding to "strongly disagree" and 5 corresponding to "strongly agree". The results of the fourth part of the questionnaire are demonstrated in Figure 10 and basic statistics were presented in Table 9.

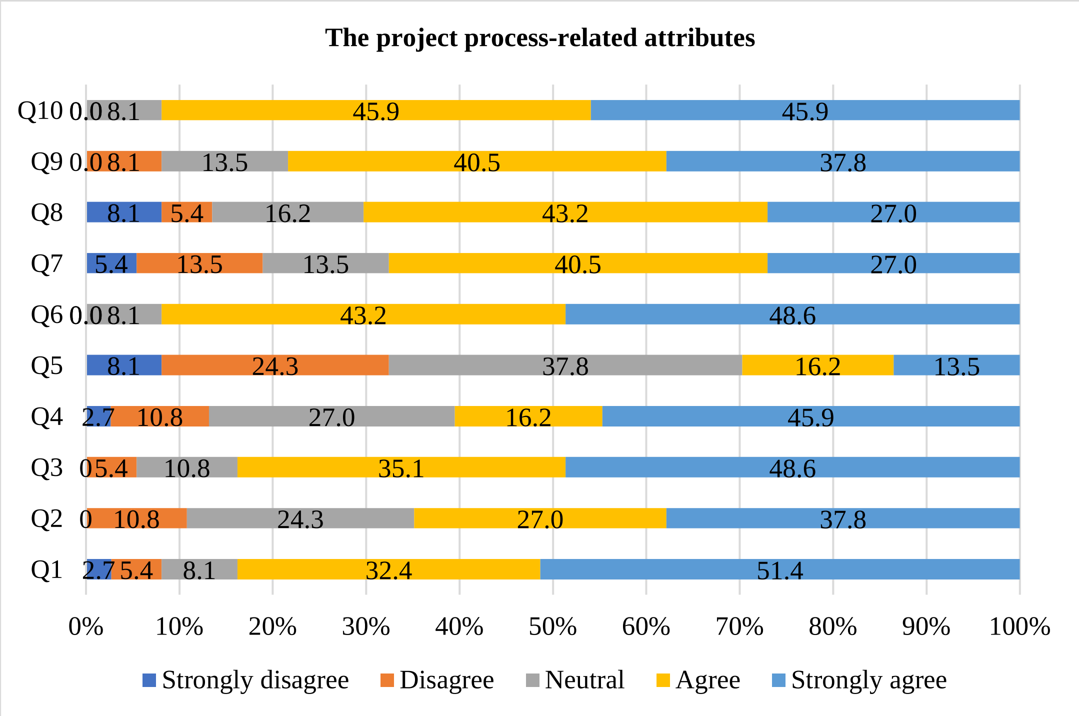


Figure 10. Results of post-project questionnaire part 4

The questions that students rated are as follows:

Q1: 3D printed motion mechanisms allowed me to learn easier.

The responses to this question were largely positive with 51.4% strongly agreeing and 32.4% agreeing and received the fourth highest overall mean of 4.24.

Q2: 3D printed motion mechanisms allowed me to learn other teams' mechanisms.

The responses to this question were mixed with 10.8% disagreeing and 24,3% of the responses being neutral. The mean of all the responses was 3.91.

Q3: 3D printed motion mechanisms provided me to notice the mistakes made in 3D computer modelling.

The responses to this question were mixed but largely positive with 5.4% disagreeing and 10,8% of the responses being neutral and received third highest overall mean (4.27) and third lowest standard deviation (0.871).

Q4: The knowledge of mechanisms gained throughout the project allowed me to create product design ideas easier.

The responses to this question were also mixed with 2.7% strongly disagreeing and 10.8% disagreeing and an overall mean of 3.73.

Q5: Obligation to use the assigned mechanism limited my creativity in the design process.

The responses to this question were largely neutral (37.8%) and received the lowest overall mean (3.03).

	Total (n)	*Strongly disagree (%)*	*Disagree (%)*	*Neutral (%)*	*Agree (%)*	*Strongly agree (%)*	*Total (%)*	*Mean*	*SD*
Q1	*37*	*2.7*	*5.4*	*8.1*	*32.4*	*51.4*	*100*	*4.24*	*1.011*
Q2	*37*	*0*	*10.8*	*24.3*	*27*	*378*	*100*	*3.91*	*1.037*
Q3	*37*	*0*	*5.4*	*10.8*	*35.1*	*48.6*	*100*	*4.27*	*0.871*
Q4	*37*	*2.7*	*10.8*	*27*	*29.7*	*29.7*	*100*	*3.73*	*1.097*
Q5	*37*	*8.1*	*24.3*	*37.8*	*16.2*	*13.5*	*100*	*3.03*	*1.142*
Q6	*37*	*0*	*0*	*8,1*	*43.2*	*48.6*	*100*	*4.41*	*0.644*
Q7	*37*	*5.4*	*13.5*	*13.5*	*40.5*	*27*	*100*	*3.70*	*1.175*
Q8	*37*	*8.1*	*5.4*	*16.2*	*43.2*	*27*	*100*	*3.76*	*1.164*
Q9	*37*	*0*	*8.1*	*13.5*	*40.5*	*37.8*	*100*	*4.08*	*0.924*
Q10	*37*	*0*	*0*	*8.1*	*45.9*	*45.9*	*100*	*4.38*	*0.639*

Table 9. Basic statistics of the results of post-project questionnaire part four

Q6: I can utilise the knowledge of mechanisms gained for further projects.

The responses to this question were largely positive with only 8.1% of the responses being neutral and received the highest overall mean of 4.41 and the second lowest standard deviation of 0.644.

Q7: Teamwork allowed us to create diverse creative product design ideas.

The responses to this question were mixed with 5.4% strongly disagreeing and 13.5% disagreeing and 13.5% of responses being neutral. The mean of all responses was 3.70 (the second lowest in the data set) and the standard deviation was 1.175 (the highest in the data set).

Q8: This project has increased my motivation to work as a team.

The responses to this question were again mixed with 5,4% strongly disagreeing and 18.9% disagreeing and 18.9% of responses being neutral. The mean of all responses was 3.76 (the second lowest in the data set) and the standard deviation was 1.238 (the highest in data set).

Q9: This project increased my motivation to the product design studio.

The responses to this question were largely positive with only 8.1% disagreeing and 13.5% of responses being neutral.

Q10: The project process was useful for me in general.

The responses to this question were again largely positive with only 8.1% of responses being neutral. The mean of all the responses was 4.38 which is second highest in the data set and received a standard deviation of 0.639 which is the lowest in the data set.

Conclusion

Although it is reported that knowledge and principles of mechanical designing is an important item for industrial designers (Liu et al., 2013), the studies on the teaching of mechanical mechanisms to ID students are limited. In spite of its importance, mechanics-based courses are generally taught through traditional lecture-based style in ID departments in Turkey. In addition, there is no integration between mechanics-based courses and design studio courses, which makes difficult for students to apply the knowledge of mechanisms to the design projects.

This paper has proposed and presented a new teaching model combining three main phases: Improving theoretical knowledge of mechanisms and possible applications, in-depth practical knowledge of specific mechanisms and application of mechanism into design a process (action learning). Integration of this teaching model to the design project aimed to improve ID students' learning experience providing transference of theoretical knowledge into practice. Furthermore, this combined teaching model covered all learning styles of K-LSI although focused on learning by doing and experiencing. Thus, it supported the notion that "design students learn in diverse ways". (Carmel-Gilfilen, 2012; Demirbas and Demirkan, 2003, 2007; Demirkan and Demirbas, 2008; Demirkan, 2016; Kvan and Yunyan, 2005). The evaluation of this teaching model focuses on project observations and post-questionnaire to analyse objectively the appropriateness of it.

Observations of project process and submissions revealed that in all three phases of the project the expected outcomes were highly obtained. All phases fed each other and the knowledge of mechanisms cumulated from the first phase to final phase. Research and technical drawings of mechanisms provided students with sufficient theoretical knowledge for utilising in the phase of practical knowledge. The practical knowledge phase reinforced the knowledge of mechanisms by transferring theory to practice with 3D computer modelling, 3D printing and animating. 3D computer modelling enabled students to comprehend the parts of the mechanisms and the relations between them. Having to model for 3D printing provided the opportunity to learn about the optimum wall thicknesses of the parts and tolerances between them. It also contributed to gaining concrete experience about manufacturing principles. These applications increased the students' practical knowledge of 3D modelling and printing. Cumulative knowledge gained throughout the project facilitated the application of mechanisms to mechanical game design project.

The results of post-questionnaire indicated that the students thought that although the most challenging phase was the application of mechanism, it was also the second most effective phase on their learning of mechanisms. Therefore, application of mechanism to a design project is vital to gain sufficient competencies for comprehending the function of the mechanisms. Studies indicate that design students are found in all stages of Kolb's learning cycle. However, diverging and accommodating learning styles (learning by doing and experiencing) are dominant and a better fit for design education (Carmel-Gilfilen, 2012). In addition, design students prefer sensing, visual and active learning styles; that is, learning facts and concrete materials, visual information and hands-on activities (Demirkan, 2016). Accordingly, mechanics-based courses in ID departments must be revised in terms of design students' learning styles. They should introduce the concept of problem-based action learning (learning by doing and experiencing) inside the learning system since this style emphasises direct utilisation of the otherwise very abstract knowledge of scientific theories. Apart from that, such courses should collaborate with design studio courses within a problem-based action-learning environment. Therefore, the further step of this combined teaching model will be the extension of the applied model of action learning model to problem-based learning through simultaneous or consecutive mechanics related course and product design studio.

The studies suggest that design students show a preference to work in teams (Nussbaumer and Guerin, 2000; Bender, 2004; Carmel-Gilfilen, 2012; Demirkan, 2016). The findings also support that teamwork increases design students' creativity and motivation. Similar to design-studio projects, collaborative projects might be adapted to mechanics-based courses.

The results revealed that 3D computer modelling was the most effective phase during the process. It supports the fact that designers are visual and active learners. Thus, assignments could be designed mainly based on visual information and hands-on activities like drawing, 3D modelling and testing. It also supports that design students prefer a sensing learning style like facts and concrete material rather than theories. The study also revealed that designers prefer visual information rather than verbal ones. As Demirkan 2016 stated, designers learn better with pictures, schemas and videos. Moreover, it is found that design students are active learners; they prefer teamwork and hands-on activities, like sketching or constructing a 3D model. They learn better by doing and applying.

The results of post-questionnaire also indicated that students agreed that the project was effective in terms of their motivation to the course and useful for further projects. Thus, the first thing to do in the product design studios is to motivate students' interest. An emphasis on case studies in practical design greatly improves industrial design students' abilities in applying mechanical design theory.

The curriculum of an industrial design programme consists of various courses; namely fundamental courses, technology-based courses, artistic courses and design studio courses (Demirbas and Demirkan, 2007; Demirbas, 2001; Uluoğlu, 1990). Since courses have different dynamics, appropriate learning styles might differ according to the type of courses. Studies found that there is a significant correlation between learning style and students' academic performance in design education (Demirbas and Demirkan, 2007; Kvan and Yunyan, 2005). Therefore, instructors should be aware of learning styles and place emphasis on specific exercises accordingly.

This study was based on data collected from 41 students and limited to one University; hence, for generalisability of results in design education larger samples are required. However, overall results of the project established that this combined teaching model of mechanisms improved ID students' learning outcomes and competencies in terms of transferring the gained theoretical and practical knowledge to the action learning through creating a game design including the concrete function of the mechanism inside the system.

Although this study focuses on the teaching of mechanisms, the general approach on implementation and evaluation could be extrapolated to other ID courses.

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How to frame the un-known? The odd alliance of design and "fundamental physics" in a design school

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Abstract

This paper analyzes the introduction of fundamental physics in design education as a pedagogical method that trains designers to create with the un-known. It studies how three workshops offered design students to work on: superconductivity in 2011, quantum physics in 2013 and light and optics in 2014. The authors observe that introducing physics in a design curriculum was thought in terms of an "a fortiori" education program that would help practitioners to come up with pertinent questions and responses even if they cannot comprehend all aspects of the problem. The authors looked at how the workshops were handled and suggest that the educational framework had five goals that correspond to a model of design: affective (how to cope with uncertainty), reflexive learning (how to cope with processes rather than contents), cognitive (how to cope with non knowledge), economic (how to cope with the industrial society of innovation), and political (how to cope with the equality of disciplines and "indiscipline").

Keywords

design education; interdisciplinarity; expansive learning; design theory; knowledge

Interdisciplinarity in design education

Design education is organized so as to teach students how to be creative (Cross, Christiaans, and Dorst, 1994; Folkmann, 2010; van Dooren, Boshuizen, van Merriënboer, Asselbergs, and van Dorst, 2013; Lu, 2015; Tovey, 2015), build a theoretical and visual culture (Brookes,1992; Dutton, 1991; Gall, 2008; Chin, 2011; Hadjiyanni, 2014), solve problems with methodological and analytical techniques (Schon & Wiggins,1992; Goldschmidt & Smolkov 2006; Adams, turns, and Atman, 2003; Ozkan & Dogan, 2013; Daalhuizen, 2014), to create industrial and social value, community of practice (Lave and Wenger, 1991, Wenger, 1998), and multi-dimensional treatment (Engeström, 1987). One of the issues of the design curricula is to help creative skills intersect with theoretical knowledge (Gentes et alii, 2015, Tovey, 2015). Some programs actually engage the students into scientific literacy with the usual argumentation as reported by Fenstein (2010): sciences are helpful even for students who do not intend to engage into a scientific career because they are part of a general education (Donnelly, 2006). Science literacy is also supposed to help people make better reasoning and therefore helps them better manage their lives. In fact, multiple interdisciplinarities exist as Huutoniemi et alii (2009), who analyze their typology and indicators, stress. In education, the definitions also vary from the lowest degree of integration to reinventing and refiguring the fields of knowledge (Klein, 2006): Lenoir, Geoffroy, and Hasni identified 8 distinct forms of interdisciplinarity (Lenoir and alii, 2001). As far as design education is concerned, Findeli (2001) points out that schools of design (such as Ulms or Chicago) relied on a balance between art, sciences, and technologies and taught various disciplines that were judged necessary, in particular because design was considered as an applied science. However, he remarks the impossibility of listing the infinite number of sciences that could be applied by design. Ezio Manzini (2009) also observed that contemporary design schools could be considered as “agents of (sustainable) change”. In his analysis, design educational programs play a fundamental role in “new scenarios for the future”, and the new challenge regarding design education is not so much to accumulate research and knowledge about everything but to know how to manage the “values of design research”. One of the consequences of what he calls “new design knowledge” is that all current disciplines can come into play to support a designing activity. This issue of managing interdisciplinarity is tackled in specific ways in professional settings (Jacobs, 1989; Luecht and alii, 1989; Austin and alii, 2001). For Manzini, co-design and the collaboration of large teams makes it possible to achieve complex projects. But in this article, we are interested in understanding how a design school can train its students towards this interdisciplinary co-design, or how to engage in a dialog with disciplines. As pointed out by Wooyoung Sung et al. (2015), most of industrial design education is based on the “studio-based design pedagogy”. The format is perfectly adapted to situations where the problem is relatively well identified. But when faced with complexity, “industrial design educators may need to consider an approach that is more interdisciplinary and that seeks solutions beyond those found in one design domain or other”. Interdisciplinarity in this educational context goes hand in hand with the increasing scope of design projects and the wider range of design productions.

In our opinion, the question is whether the interdisciplinarity is conceptual (search for meaning) or instrumental (functional aim) or, as we make the hypothesis, “expansive”. By expansive, we mean “constructing and implementing a radically new, wider and more complex object and concept for their activity” (Engeström and Sannino, 2010). From this point of view, the goal would not be so much about teaching *designerly way of knowing* (Cross, 2001), but to provide with different modalities supporting “expansive learning” (Engeström, 2001).

Our hypothesis is that interdisciplinarity in design can be better understood if we look at the characteristics and properties of these interdisciplinary situations to understand how they can actively support invention. How do students learn how to handle interdisciplinarity in action, through workshops, documents, and artifacts? To answer these questions, we describe 3 design workshops called “Form and Material”, organized and supervised by a professor in fundamental physics (Z), and two designers (X) and (Y). In the analysis, we focus on how the different actors frame the workshops: explain it to students, organize the interactions, pace the design work. How do they manage not only the knowledge but also the non-knowledge (Mathieu and Schmidt, 2014) that goes with collaborating with other disciplines? How does this interdisciplinary framework support an expansive learning rather than a cumulative one?

Based on the observations and interviews, we present five properties of this framework: affective, cognitive, reflexive learning, economics, and political. These properties presuppose a model of design and design education. Finally, we will propose a conclusion about this *a fortiori* strategy in design education and how it relies on expansive learning.

Field work: interdisciplinarity in practice

Context: an unlikely encounter between design and fundamental physics

The analysis of the literature on design shows numerous collaborative programs between Science and Design (Cross, 1993, 2001; Bruffee, 1999; Stahl, 2006; Renon 2015). While interdisciplinarity is advocated by educational institutions and sustained by the analysis of professional design practices, many students who are introduced to design interdisciplinarity are afraid of the vast array of disciplines that they should know and use. The question is how to train for an almost infinite set of knowledge? Is it even possible to do so or is it a myth? And how are students prepared to raise up to the challenge of not understanding the depth of other disciplines that they must work with?

To address these questions, we chose to study a series of collaborations, engaged since 2011, between a professor in fundamental physics who is also one of the authors of this paper and designers in a design school. Investigation of fundamental physics problems by design is not entirely new (Kelly, 1959; Chi and Glaser, 1979; Chi and alii, 1981; Chii and alii, 1989). However, it is still an institutional exploratory space for design education. We chose this experiment first because it is a test bed for pedagogical explorations of the relations between science and design. We also chose it because one of the authors (JB) could participate in the different stages of the project, from its definition to its implementation allowing for a longitudinal approach.

The opening of workshops “Form and Material” to fundamental physics

The “Form and Material” workshops gather each time about fifteen to twenty design students of mixed backgrounds and levels but with no specific qualification in science. They are supervised by two professional designers (X) and (Y) and a physicist (Z). For each workshop, a physics theme is chosen by the designers and the physicist together among the areas of expertise of the physicist: superconductivity in 2011, quantum physics in 2013 and light and optics in 2014. Focus is put on fundamental topics and not so much on technologies or applications. For example, the quantum physics project focuses on basic quantum phenomena such as wave-particle duality or tunneling effect. The light project focuses on the electromagnetic and quantum nature of light, not on technologies of lightings. During the workshops, students are first given outreach seminars by the physicist together with visits to the physics lab and open discussions about the physics at play. The students are then asked to conceive a design project inspired by the scientific material during a four-month period with two days per week devoted to the workshop.

There is a certain latitude in the definition of what the students’ projects are going to be useful for. Their project can address a pedagogical goal and serve for outreach purpose, for example videos displaying physics phenomena, or devices demonstrating physics experiments. But the projects can also end up in artefacts inspired by science but with no educational purpose, for example lightings, clothes, or jewels. Students are encouraged to experiment various formats and domains. These workshops explore a wide variety of subjects (physics education, but also security, games, food, household use, sound, art, sport…), thanks to the help of the teachers-designers who make sure that every student explores a different path. The resulting projects are then shown to the rest of the school in a collective presentation and exhibition. They are also displayed in videos gathered in a website (ref : www.supraconductivite.fr www.designquantique.fr www.lightsciencedesign.fr) and further used in various outreach activities: exhibits in science museums, outreach talks, science fairs… A detailed description of the artefacts produced by the students can be found in Bobroff et al. (2014) for superconductivity and in Jutant and Bobroff (2015) for quantum physics.

Research methods

One of the workshops has already been described and analyzed through a participative observation and a semio-pragmatic analysis of the documents and artifacts produced by the students by Jutant et Bobroff (2015). Elaborating on Jutant and Bobroff, who pointed out the diversity of popularization strategies deployed by the students, we wanted to analyze the framework of these activities that give the ideological background, the legitimization of the production, the specific "episteme", that is the presuppositions that found the practice and *a priori* knowledge of this experience ("that defines the conditions of possibility of all knowledge, whether expressed in a theory or silently invested in a practice", Foucault, 1966, 168). We therefore did qualitative interviews with the actors post workshops with a focus on how the proposition of the workshops had been framed (Becker & Geer, 1957; Tedlock, 1991).

Analysis of the "odd alliance"

The experiment that we describe was not planned as such, as the director of the school at that time points out. The "natural partnerships" of the design school are more with engineering sciences. The interviews with the different actors of the projects confirms this exploratory dimension of the project. An encounter between fundamental physics and design can be surprising. As it was a first occurrence in the school, a number of methods were used to make sure that the students would be able to tackle the challenge. A first 5-day collaboration with the physics professor was undertaken to "test" the feasibility of this collaboration and to reassure the students and the different actors of the project. As this first step was successful and the students were enthusiastic, the direction of the school and the faculty decided to do another, longer, 4 month workshop the following semester of the same year. All the subsequent workshops followed the same format which include elements of speech (such as the goals of the students productions), and pedagogical organization.

1. The students have the freedom to explore the subject with any medium they choose, as they are supposed to take a "posture" of designer. It is not a question of truth or error but how to acquire a "position" towards a body of knowledge.
2. The physicist is present all along the workshop. It starts during the presentation of the different workshops to the students, since the physicist and the designers present the "physics and design" workshop together. Then the physicist attends the workshop about two to three times per month. According, to him and the supervising designers, it allows a more trustful and open dialog with the students. After a few weeks, they don't hesitate to ask questions:

   "It seems that my presence has a comforting effect: the fact that I'm enthusiastic about their productions and accessible on the science side seems to reassure and motivate the students."

   In any case, the presence of the physics teacher is very important. When he is present at the workshop, the students want to do their best to show him their productions. So, each time he comes, we observed moments of acceleration of production, and new exploration and consolidation periods.
3. The physical presence of all the actors during the workshop emphasizes the collaboration. Even before producing anything, the students can anticipate a certain form of complementarity. There is a dramaturgy of the collaboration as well as an effective contribution of all the participants. In addition, there is the staging of an equality of disciplines. Science is not above design (the physicists: "I

guess this perhaps reassures the students that I'm reachable and enthusiast about this collaboration".) The claim of the experiment is that each body of knowledge (design and science), looks at the others' competence with "ignorant eyes" (Rancière, 1991). As the physicist says:

"I am not a designer, I will not teach the students how to do design. In the same way, they are not physicists, and I won't expect them to become so."

In other words, the actors insist that the identity of the participants is not changed by the experiment. Still a collaboration is presented as possible. The workshop is the way to materialize this collaboration in practice.

4. To encourage students in exploration, the physicist qualifies different levels of integration between their activity and scientific knowledge. As the physicist says:

   " - I also insist that I don't expect them to understand every aspects of the physics at play: they can be "superficial" in their understanding. Also I make it clear that I will be there often and available to discuss and provide explanations as much as needed."

   As he mentions, sometimes the students want to make "pedagogical" projects which explain physics:

   " - In this case only (not the most common), I'm more demanding on the science exposed in their projects, and I ask for a validation process where I'm allowed to correct the scientific part if needed."

   The productions can and will be used in scientific communication contexts such as exhibitions, websites, science museums … The work done is therefore validated outside of the workshop. This gives an additional value to the students' productions. This validation is a guarantee that their work is meaningful in a scientific context.

5. According to the actors, the framework also manages a passage of the abstract to the concrete. One of the supervising designers said that she was disconcerted by the choice of quantum physics in particular, because, as she says:

   " - It was very abstract and made it difficult for the students to project themselves in objects".

   To counterbalance the abstract dimension of the project, the students were invited to visit the physics lab "to anchor the workshop in tangible places of scientific practice." Another method was to resort to usual and well-known design methods. As one of the designers pointed out:

   " - We asked the students to use a method they know well, the scenarios of use, so that the project appeared "same as usual". We wanted to reassure the students on the objects they would have to produce, and by this way remove inhibitions they may have with the scientific knowledge they are not supposed to *have*."

Discussion: the five properties of the "design and physics" experiment

From the interviews and the observations, the framework appears to have several properties that build a specific dispositive made of language, organization, places, interactions, that structure the distribution of power between the actors and the disciplines (Foucault, 1975).

1. It is an *affective* dispositive. The new workshop is considered as a destabilizing environment. Indeed, the design students with no scientific background are faced with fundamental modern physics involving abstract concepts which may involve sophisticated mathematics or high-tech tools. Destabilization

also occurs about the image of science itself, not embedded in applications or technologies, but from the point of view of fundamental research. However, the director shows his confidence that designers can elaborate within such a difficult environment. For him, trust in the design students' capacity to grasp elements that are beyond their usual skills and knowledge is at the core of this operation. As we have seen in the previous section, the charismatic ("enthusiastic") presence of the physics professor is a part of the affective dispositive as well as the reassuring collective or individual discussions. The figures of power and knowledge also frame the affective challenge with legitimate authority. The underlying model of design is that it can be a psychological challenge that has to be managed with care and attention.

2. It is a *reflexive* and an *"expansive learning"* (Engeström, 2001) dispositive: the emphasis cannot be on "contents" since there is little chance that the design students will be able to catch notions that require years of training in physics. They get some elements of contents through the course given by the physicist, but they are mostly encouraged to gather their creative and making skills. There is therefore an abrupt shift from relying on learning something or learning how to make something, to using skills learnt in different classes and to put these skills into the project. The director is acutely aware that it is a particular challenge because he observes that students have difficulties to put into practice something they have learnt in one class to another class or workshop. The dispositive is therefore not only centered on the capacity to reuse some competence learnt elsewhere, but also, because of its extreme qualities, it is a reflexive space on this particular practice since physics is not a class "proper". The class is a test bed of designing through experience which is one of the design activity profiles analyzed by Cross (2001) and Cross and Kruger (2006). Designers explore their own past and tap into their previous realizations so as to find similarities with the new design projects. During the workshop, the students have to do the same and actually think about this way of doing design. It is also congruent with the model of the "reflective practitioner" described by Schön (1983, 1987) that is a rationale that is based on doing and stepping back.

3. It is a cognitive dispositive (Rusbult, 1997). Though the professor in physics tries to give as many vivid metaphors as he can - for example, he presents the quantum tunneling effect as if, when an object is projected onto a wall, a small tunnel opens up and lets the object go through; or he presents superconducting levitation as a giant invisible wave embedded in the material which swirls when a magnet approaches and repels the magnet - the students have to work past their non-knowledge to be able to produce an artifact or a representation. Some students even acknowledged the fact that *not* understanding the topic in-depth was a liberating factor in terms of creativity, as designers and physicist looks at the others' competence with *a priori* "ignorant" eyes (to use Rancière's expression in the "Ignorant Schoolmaster"). This is congruent with a theory of "projection" and transfer in design (Chow, 2009; Chow and Jonas, 2009). Designers bring together elements (whether facts, aesthetics features, concepts, methods) that apparently have nothing in common in a surprising way and create a new concept/ artefact. This unexpected encounter of seemingly unrelated elements is not only as in Pierce's logics (Peirce, 1906) the way to find new hypotheses for facts. More importantly from a design perspective, it allows to create an unknown object. As the physicist says: "I'm here to discover new types of innovative and often unexpected points of view on my own scientific field, in terms of formats, representations, and understandings, which I can then reuse in various outreach contexts". Based on Peirce's definition of creative abduction (Roozenburg, 1993), we can consider that conception happens dynamically with concepts that are neither true nor false. These concepts or projects of

artefacts, force the participants to look for solutions or knowledge that could bridge the gap between the fields that are brought together.

4. It is an economics dispositive. Even if the body of knowledge is not expected to change with the experiment, students work with the uncertainty of the possible applications of scientific knowledge, and more broadly speaking with the uncertainties of the identity of objects. For example, a student conceived a wooden artefact to mimic some mathematical representations of wave functions. This artefact originally designed for a specific use in an outreach context in science museums happened to be used later in education as an introductory tool to help physics students think about the concept of the wave function and, on the other side, in a design exhibit (Biennale de Saint-Etienne). This seems to be an adaptation to the general mode of uncertainty that affects contemporary economics under the rule of radical innovation and that was pointed out by researchers in design (Morello, 2000) as well as in management and organization sciences (Le Masson, Weil, Hatchuel, 2006). Contemporary objects have no stabilized identity and designers cannot count on traditions of use for their objects. The director is quite clear about this: "nothing is going to be the same in twenty or thirty years from now. I want to make sure that designers will have the skills to adjust to an ever-changing environment". The shift from knowing something and knowing how to make something to knowing a posture of continuous adjustment to a changing set of environmental data is at the core of the dispositive. This kind of collaboration is the way to materialize this "changing environment" in practice.
5. It is a political scientific dispositive. The workshop organizes a form of emancipation (Rancière, 1991, 2009) from academic disciplines. First, the disciplines are represented by the professors participating in the workshops. The professors reinforce a sense of disciplinary identity by repeating that they will not change or become a hybrid between design and science. But at the same time, they offer a representation of the relations between disciplines that frees the participant of a strict and closed definition of disciplines. First, contrary to what happens most of the times between sciences, there is no hierarchy between disciplines. As suggested in the previous section of this article, the workshops stage and put into practice an equal collaboration. Second, since it is assumed that they will not become physicists, students are allowed to disregard the usual path to learning physics. This is made possible by a clear initial agreement with the scientific partner that the produced artefacts do not need to be necessarily scientifically accurate. There is still a relation to science. The workshop is like a shortcut that privileges borrowing facts, theories, images, from a discipline, rather than using a structured disciplinary body of knowledge. This seems to be the case for all the actors that agree to play out of their leagues since the physicist is no designer, the designer is no physicist and there is a general agreement that there are other ways of building knowledge than accumulating it.

Conclusion: design and science in education: a framework for expansive learning

Studying these experiments, we had multiple goals:

- Beyond the particularism of these examples, what are the properties of these experiences and can they be replicated in different institutions?
- What kind of learning is targeted by educational frameworks that bring together design and sciences?
- How do these experiments teach us something about design as conception?

Contrary to what could be expected, the physicist is not there to fill up the gaps of knowledge in physics. While the interviews show that some students are more literate in physics at the end than at the beginning, the purpose of the curriculum is not to turn them away from design in the direction of physics, in a movement from “incompetence” to “competence”. The introduction of physics in design education is not primarily for the sake of “contents”, nor is it entirely for the sake of physics. In these workshops, the interdisciplinarity of design does not rely on an illusion of universal knowledge either within one person or even a group. The interdisciplinarity is not thought in terms solely of the addition of knowledge bases, or people representing these different knowledge bases as observed in innovative companies.

In the framework that we analyzed, interdisciplinarity does not appear to be conceptual in the sense of articulating two disciplinary fields together that would finally fit thanks to the emergence of new mutual concepts. The field of physics is not presented as being challenged by the field of design nor the field of design is impacted directly by the discipline of physics.

Finally, interdisciplinarity is not “instrumental” in the sense that physics as a science would need design to accomplish some of its goals, or design would use physics to pursue its tasks.

To come back to our initial question whether the interdisciplinarity displayed in these workshops is conceptual (search for meaning) or instrumental (functional aim), we can therefore say that it is neither. But something is nonetheless accomplished through the introduction of fundamental physics in a design curriculum. By bringing a discipline without *a priori* overlap with design knowledge, the workshop is an exploration of what is fundamental about design practice and knowledge. The whole framework makes an a fortiori demonstration of what design and design learning is about.

As we have seen in the discussion, it makes a demonstration of the capacity of designers to cope with five major properties of design situation: design can be a psychological challenge because it shows the limits of design knowledge not only on a personal level but because of the actual disparities between disciplines; it is a reflexive process where designers tap into their personal history and experience to create new representations at the crossroads of disciplines; it is a cognitive challenge since it deals with non-knowledge in the projection towards an X (unknown object); it is an economic challenge since there is no stability of objects in a society of continuous innovation; finally it is a political claim about the relationships between disciplines that neglects their boundaries and hierarchy.

The framework is designed so as to rehearse and cope with these difficulties. It points to a model of design and learning in design that involve expansive learning as defined by Engeström and Sannino (2010). By expansive, we mean “constructing and implementing a radically new, wider and more complex object and concept for their activity” (Engeström and Sannino, 2010).

First, the framework relies on the reasoning that who can do more can do less. Namely, if a student follows this type of workshops, he will “a fortiori” be able to participate in any other interdisciplinary project, especially those that involve science. The five different properties of the workshop are probably more or less present in the other workshops but the latter pushes their logic beyond the ordinary. If one can learn how to design in such conditions one will be able to design in all circumstances.

The response to the challenges of design situations as they are staged through the workshops is to promote expansive learning because it is learning about expansion: the tools, the frameworks, the personal and group dynamics, the way to learn… The design students are not supposed to learn something that they wouldn’t know yet, but to construct their own knowledge and imagine objects and practices, by their “non-knowledge”.

The introduction of physics in the workshops therefore played a reflexive role on design practice, not because design knowledge must include more and more disciplines but because it can deal with all the principle challenges of any design situation.

In our research, understanding how the situation of learning was framed was therefore fundamental but is not enough to see how design in practice solves the tensions that such a strange encounter brings. As students are not asked to adopt reproductive gestures, but productive postures, our future research (similar workshops are programmed in the course of 2016 with the same protagonists) will evaluate how the students actually use their capacity of projection, transfer and hybridization, build artifacts, scenarios, and other students' productions, as well as the nature of the displays (in their "plastic artwork" properties), and the evaluation of the objects (in their diversities) to solve the interdisciplinary tensions.

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A New Paradigm for Design and Technology Education?

Williams, P.J. and Stables, K. (eds) (2017). Critique in Design and Technology Education. Singapore: Springer Nature.

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Review by Matt McLean, Liverpool John Moores University

One might expect a book exploring critique to intrigue, baffle, irritate and reassure in roughly equal parts, and Critique in Design and Technology Education does not disappoint on that measure! I have titled this review 'a new paradigm', with the question mark acknowledging that it has had a place from the beginning of the subject in England and Wales (cf DES and WO, 1988), albeit largely eclipsed by designing and making. It could just as well be thought of as indication of a coming of age.

> "Our view is that such practical involvement is fundamental to an education of this kind. There is, however, an additional dimension to consider and this entails critical reflection upon and appraisal of the social and economic results of design and technological activities beyond the school… Furthermore, technological revolutions are irreversible; no technological change can be uninvented after it has taken place. We need to understand design and technology, therefore, not only to solve practical problems, to invent, optimise and realise solutions, but also so that we can acquire a sense of its enormous transformatory power." (DES and WO, 1988, p.5)

Critical analysis and evaluation has been a theme running through successive English and Welsh National Curriculum programmes of study; from critical thinking implied in the "satisfying needs and addressing opportunities" section in the first programme of study (NCC, 1990, p.31) to developing "a critical understanding of its impact on daily life and the wider world" in the current purpose of study (DfE, 2013, p.1). Arguably the gradual shift in focus in the National Curriculum and classrooms from artefacts (cf NCC, 1990) to products (cf DFE, 1995 to present) drew attention to objects rather than impact. 'Critique in Design and Technology Education' provides a theoretical starting point for educators and researchers in the subject to reflect on the role and nature of design and technology in the curriculum.

For readers unfamiliar with critical theory, it may be helpful to borrow a quote from Steve Keirl's chapter, 'Critiquing as Design and Technology Curriculum Journey, History, Politics and Potential' regarding the inherent assumptions and perspectives, an overt theme through the book and congruent with its aims:

> "Critical theorists begin with the premise that men and women are essentially unfree and inhabit a world rife with contradictions and asymmetries of power and privilege. The critical educator endorses theories that are, first and foremost, dialectical; that is, theories that recognise the problems of society as more than simply isolated events of individuals or deficiencies in the social structure." (McLaren 1989/2009, p.61 in Keirl, 2017)

The authors present a wide range of perspectives around design and technology activity stretching and challenging in roughly equal measure; thus espousing the ideas of critical theory. Some chapters may stretch the reader's understanding of the nature of design and technology, and its influencing factors, including philosophical (de Vries, pp.15-30) and spiritual (Petrina, pp. 31-49). Others take you deeper down the “rabbit hole” of design (Spendlove, pp. 71-86; Stables, pp. 51-70) with contemporary thinking on design thinking and education. Whereas, for western readers, Gumbo (pp. 87-105) challenges assumptions and bias, presenting an alternative perspective of technology and design and technology education through the lens of “indigenous knowledge systems”. And this is just in Part 1, setting “The Basis of Critique” (Williams and Stables, 2017, pp. 15-105)!

In Part 2 the authors guide the reader in critiquing aspects of design and technology education, bringing their particular pedagogical and research interests, expertise and experience. Keirl (pp.109-134) invites the reader to view curriculum development through a lens of critical theory, with practical insight for design and technology in Australia. Williams (pp. 135-152) considers the nature and importance of critique as a disposition, inextricably linked with intentional action, whilst recognising the challenges assessing it as a component of design and technology activity. Nicholl (p.153-172) and Ginestié (pp. 193-212) consider societal factors, with Nicholl espousing inclusive design and Ginestié reflecting on the technology education curriculum in France. McLaren (pp. 173-192) speaks into teacher education and teacher reflection, acknowledging the “complex and messy” nature of critiquing (p.190).

Part 3 moves towards application of critique, Seery (p. 255-274) developing the central theme in design and technology of modelling, reframing it as a form of critique. Barlex (p. 215-236) takes the relatively new idea of disruptive technologies, such as additive manufacture and the Internet of Things, providing frameworks to support critique through product life cycles, scenarios and narratives. Wilkinson (p. 275-300) applies critique to the product lifecycle and the implications for education, whereas Axell (p. 237-254) takes critique in design and technology into children’s literature and technology, a notation that secondary teachers may find novel and can learn from multidisciplinary practices in primary classrooms. In closing the section, von Mengersen (p. 301-320) considers critique as a signature pedagogy in design and art, and the “perceived dichotomy between ‘making’ and ‘knowing’…” (p. 306).

In reading this book, I repeatedly found myself starring into space lost in thought and only a few paragraphs into a chapter; so encourage the potential reader to allow time to read-think-reread-repeat. This is an essential read for the thinking design and technology teacher, teacher educator or researcher. Prepare to be challenged. Prepare to be bamboozled. Prepare to think. But read it nonetheless.

Williams and Stables’ (2017, pp. 1-12) “…About the Book” introductory chapter provides an excellent and detailed synopsis of the book and summaries of themes and chapter content, which is available online.

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Contemporary Research in Technology Education

P. John Williams and David Barlex, (eds) (2017) published by Springer

Review by Jason Davies, Cardiff Metropolitan University

eBook - £56.99 - ISBN 978-981-10-2819-9

Hardcover - £72.00 - ISBN 978-981-10-2817-5

This is an excellent book that has been published to encourage and engage teachers in research informed practice. There are eleven international research projects that focus on a range of design and technology issues

Chapter 1, Introduction written by the editors breaks the book down into four clear sections: Broad Approaches to Engaging Pupils with Designerly Thinking which draws together three pieces of international research which focus on applying this methodology in different settings. The second section: Focused Teaching and Learning in Technology Education addresses the complexity of teaching a wide range of challenging topics within technology education and the benefits of addressing real rather than abstract problems. The third section: Classroom Talk reviews the importance of communication across phases providing an overview of pupil experience and background and the final section: Communities of Practice focuses on three different communities that come together to support each other in different contexts. This introductory chapter clearly sets the scene for some interesting and relevant research that can impact upon our practice.

Chapter 2, Ideas About Design: Towards Appropriate Pedagogy for Teaching Design at the School Level written by Farhat Ara (India).

This paper explores pupils understanding of design, it highlights pupils' initial ideas of design being simply a decorative outcome. The author explores the depth and breadth of knowledge required to teach and learn effectively. Farhat presents a number of solutions to encourage this practise and to solve a wide range of problems using different frameworks and principles.

Chapter 3, Fostering Deep Learning and Critical Thinking Amongst Net Generation Learners written by Matthew Watkins (England)

An interesting application of audio-visual resources designed to engage the Net Generation and to develop their critical thinking skills within HE. Opportunities for applying this to secondary education and the opportunity for delivery by non-specialists were highlighted as possible developments.

Chapter 4, A Case Study on Problem-Solving Based on a Design Process in a Middle School Invention Class written by Jae-Young Yu (South Korea)

An interesting paper that reviews how pupils adapt a design process to solve a problem within a team. Brainstorming was engaged throughout the process and the evidence presented shows that the cycle was far from sequential.

Chapter 5, CAD and Creativity at Key Stage 3 written by Deborah Winn (England)

A timely chapter given the range of resources available for teachers and students which in itself creates problems in terms of experience in using and teaching CAD. The action research study took place with four different groups of students each of which made suggestions as to how the learning could be improved to increase engagement and understanding. A simple resource was developed to support pupils as they progressed through the 3D CAD software and this was implemented within the research to support pupil pairings.

Chapter 6, Mixed Media Modelling of Technological Concepts in Electricity written by Sarah Pule (Malta)

This chapter examines how learning can take place within engineering and technology, specifically the field of electricity. Learning resources focus on visual and kinaesthetic learning and relate closely to the familiar standard electrical symbols. Further developments highlight the idea of embodied cognition and how this should encourage teachers to make concepts visible and tangible to students.

Chapter 7, Difficulties in Teaching and Learning Sectional Drawing in a University Based in the Eastern Cape, South Africa written by Samuel Khoza (South Africa)

A qualitative and quantitative study that focuses on HE students studying Engineering Graphics and Design. Issues surrounding how sectional drawing is taught and learnt are discussed which includes a lack of experience prior to entering HE. A number of recommendations are made including a focus on line work and drawing models to develop visualisation skills.

Chapter 8, Let's Get Kids Talking in Technology: Implications for Teachers written by Wendy Fox-Turnbull (New Zealand)

How can talk play a role in learning technology? A very interesting piece of work set in the primary classroom. Participants were given cameras to take photographs to discuss later – 'autophotography'. The use of disposable cameras also prevented students from deleting pictures. The paper identifies three strategies that teachers can use to improve teaching and learning by using their initial knowledge, their cultural knowledge and to encourage intercognitive conversations amongst their students.

Chapter 9, Teaching Bioethics: The Intersection of Values and the Applications that Advances in Technology Make Possible written by Deborah Stevens (New Zealand)

A challenging and thought-provoking chapter that questions the developments in science and technology that pupils will encounter when they have to make choices. How do we ensure they are ethically prepared citizens? Stevens' research identifies a wide range of contexts and strategies that support effective teaching of Bioethics.

Chapter 10, Exploring the Role of Professional Learning Communities in Supporting the Identity Transition of Beginning Design and Technology Teachers written by Denise MacGregor (Australia)

The first year of a teacher is one of the most important and how this is managed will affect the progress of that individual. The author draws upon evidence from five case studies and highlights two major mentoring roles that have a significant impact upon progress. There is also a need to evaluate good practice of current mentoring programmes and to identify aspects that can be shared through professional learning communities.

Chapter 11, Technology Education Teachers' Professional Development Through Action Research written by Tomé Awshar Mapotse (South Africa)

This chapter highlights the challenges that developing countries face with Technology Education and the need to further develop unqualified and underqualified teachers through action research. It is clear from the research that the starting point for experience was very low. The author identified a number of areas that teachers could access to help improve their knowledge and skills including identifying a local university. Finally, he identified a six-week programme to empower teachers through action research.

Chapter 12, Technology Education: Education for Enterprise (E4E) in New Zealand (A Connected Curriculum) written by Gary O'Sullivan (New Zealand)

This chapter focuses on the development of technology and enterprise education as equal partners but as a creative connected curriculum. Education for enterprise was successful when education partners allowed for a closer network between their areas of learning. Success came from practical and tangible projects that were often linked to local requirements. Authentic contexts provided engagement throughout the curriculum.

Overall this is a well-balanced book that provides a basis and focal point for up-to-date research informed practice. The chapters draw on many areas of Technology that will have impact upon our practice as well as forming the basis of discussion and improvement.

I recommend this book for design and technology practitioners who are interested in academic research and the structure it needs to take to ensure it is valid and reliable.

My only concern is the cost of the book, but I am sure most universities will keep a copy on the shelf for reference.