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Design and Technology Education: An International Journal

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Dr Lyndon Buck, Buckinghamshire New University, UK
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This first issue of a new decade (who knows what we'll all end up calling the 2020s) gives us a chance to look forward to new and developing pedagogies for the upcoming decade along with some focus on the challenges facing us in design and technology education. It also provides an opportunity to reflect on the past, and to remember some of those who have contributed so much to our profession, and inspired so many of us through their skill, dedication and enthusiasm. Many of us in the UK will have known and fondly remember John Penfold who died last year aged 89. John first taught craft, design and technology in secondary schools before he became a lecturer and senior lecturer at Shoreditch College, later to become Brunel University's Runnymede Campus in Englefield Green. John remained there for over 30 years, sharing his skills with many trainee design technology teachers (such as Kay's husband Tony Lawler) and later with Brunel's first cohorts of industrial design students (including Lyndon from 1987 - 1991).

His family is particularly proud of a conference he helped to organise in 1978 in Englefield Green for 400 girls at which they were encouraged to think of jobs in design technology. Throughout his career he promoted teaching careers in CDT with a particular emphasis on attracting women to STEM teaching. He used his holiday periods to work for UNESCO training future teachers and in Malta and Indonesia. John also founded the History of Design group for the University of the Third Age, which held monthly meetings at his house in Dedworth, Windsor. His house boasted an impressive workshop and he built all of the wooden furniture and flooring as well as many beautiful figurines. His first degree in economics was followed by a master's degree in the role of education in manual subjects, research for which led to the publication of his 1988 book *Craft, Design and Technology: Past, Present and Future*. Kay and Richard Kimbell would later cite this work in their piece *Methodologies: Approaches to Understanding Design Technology* in the 2006 *International Handbook of Design Technology: Reviewing the Past Twenty Years*. One (5 star!) Amazon review of John's book simply reads "Lovely – a blessing to own".

His son Julian said: "He was a modest man but he had so much knowledge. He would amaze you because there was nothing he could not talk about" (*Talented craftsman who inspired generations of future teachers has died*, *The Royal Borough Observer*, Windsor, 5th September 2019). John was a renowned expert on William Morris and lectured widely on him and his work. He took early retirement from Brunel in his 50s to become an educational consultant to many other universities and colleges, including the development of the furniture design and craft degree and industry training courses at Buckinghamshire New University, UK (then BCHE), and was a GCE examiner in schools. John's daughter Sarah Feazey captures him perfectly in her *Guardian Education* obituary of 31 December 2019 when she describes him as “funny and considerate, he was a family man, as well as a genial host, loyal friend and raconteur”. He will be warmly remembered and missed by many.

In this issue’s reflection piece **KEF, TEF, REF and all that: The current state of art & design higher education in the UK** Jake Kaner (Nottingham Trent University, UK) discusses the suite of 3 framework metrics that are intended to measure the totality of impact of UK HE. Vice chancellors from humanities and arts-focused institutions in the UK have long expressed major concerns about the focus of these frameworks and the threats that they pose to arts and humanities education, with few measures to account for non-financial impact across disciplines. The ongoing development of these 3 frameworks and their impact on the sector should certainly be carefully monitored by those of us involved and interested in UK design and technology education. It would be interesting to see how the UK experience of working alongside and within these frameworks reflects what is happening in other countries, and whether this resonates with those working outside of the UK HE sector.

This issue contains six articles which describe new approaches to making students reflect on their developing design skills and their own personal development. The first two articles in this issue explore ways in which students can begin to more fully understand, develop and apply their own creative thinking skills and design processes.

In **Making the design process in design education explicit: two exploratory case studies**, Elise van Dooren, Thijs Asselbergs and Machiel van Dorst (Delft University of Technology, The Netherlands), Els Boshuizen (Open University and University of Turku, Finland) and Jeroen van Merriënboer (Maastricht University, The Netherlands) consider the perceived overreliance of many design courses on the final student outcome or product rather than the design process used to achieve it. By developing a framework and a tool for students and teachers, it is hoped that students will begin to understand and articulate the design processes that they are using, increase their ability to use these processes, and help them to use them more effectively. It is certainly true that art and design students often struggle to articulate what transferable skills and subject knowledge they have gained during their studies, even when their work shows great personal and design development. In an educational environment where outcomes need to be explicit and constantly measurable through an increasingly expanding range of metrics the development of this tool and a commonly shared design education vocabulary is timely. The case studies seem to suggest an increased student willingness to engage with formal design processes, evidence of more experimentation, less stress and more enjoyment, and an increased ability to reflect on their personal development.

In **Critical Thinking in Problem Exploration in Design and Technology Design Project** Wei Leong Loh (Kyushu University, Japan) uses student design journals to study the intellectual standards for reasoning in design problem exploration. The quality and variety of sources used played a key role in the accuracy of the research data used, along with a baseline level of background knowledge necessary to be able to clearly articulate and conceptualise the design problem. But it is shown that the development of intellectual standards for reasoning is a key requirement for students to develop critical thinking skills and be able to apply these in their design work. Dealing with ambiguity, and being able to conceptualise and frame a problem, is a key skill which requires well developed critical thinking skills. By increasing students' awareness of the intellectual reasoning that they are employing, often without realising it, within their design work, it is hoped that teachers can develop deeper, more objective and more critical thinking throughout the design process.

The next two articles describe new approaches to developing the design student toolkit, introducing new ways of working and new ideas and allowing new ways of seeing and doing.

In **Digital Touch: Towards a Novel User-Experience Design Pedagogy** Val Mitchell and Garrath Wilson (Loughborough University, UK) and Cary Jewitt, Kerstin Leder Mackley, Lili Golmohammadi, Douglas Atkinson and Sara Price (University College London, UK) reflect on the rapid growth of human computer interaction (HCI) and user experience design (UXD), and the merging of many disciplines within these new fields. A collaboration between HCI, industrial design and social science teams has resulted in a novel pedagogy using low fidelity prototypes for digital touch experiences, and the development of a Designing Digital Touch Toolkit to assist in the learning and teaching of user experience and human centred design. The use of sensory-experiential prototyping materials to explore digital touch helps students to understand, contextualise and articulate the user experience and to construct product narratives around these. The resulting toolkit aims to explore the intersection between physical and digital materiality, which may help to produce more meaningful, memorable and insightful user experiences in future digital products.

In **A Biomimetic Design Experience in Informal Interior Architecture Education** Umut Karsli (Istanbul University, Turkey) and Serpil Özker (Isik University, Turkey) explore how biomimetic design techniques and learning from nature can inspire students in spatial design and interior architecture projects. While biomimicry has become widely recognised in design circles as a tool for encouraging creativity and innovation in design, it continues to be a problem for students to find ways of applying it in their work. The authors here compare solution-driven or "biology push" and problem driven or "technology push" approaches and consider which is more appropriate at different stages in student curricula. The also consider the appropriate level of abstraction to enable students to understand and apply the biological processes and processes that they are studying. The development of a *BIOStructure Workshop* allows students to experience biomimetic design in an informal educational setting which encourages collaboration and creativity. It is interesting to note the shift from being inspired through form-oriented solutions to more abstract functional processes of the natural organism or process that they are mimicking as the students progress through their studies. It is hoped to further implement a biomimetic approach in the design studio and to open this out to students from other disciplines such as biology. By helping to demystify nature and demonstrating what biology can teach us, we may be able to inspire designers to use biomimicry more creatively and apply it successfully to a much wider range of design problems, and to create more innovative, sustainable solutions.

The final two articles highlight the importance of delivering new technologies and ways of working into the curriculum in a meaningful way in order to ensure student engagement.

In **Framing craft and performance in hybrid puppetry workshops** Michael Nitsche and Crystal Gillett (Georgia Institute of Technology, USA) describe their *Prototyping Puppets* project mixing craft and performance to engage students in STEM and help to demystify technology such as electronics. Through basic puppet making and puppet play students showed self perceived increases in their attitudes towards technology and helped them to move away from "black boxing" of technology and engage more fully in the activities, inspiring students to tackle rather than hide the underlying principles. Workshops delivered using teaching materials developed from the project showed increased student engagement and perceived positive attitude changes towards art and craft, and a successful integration of technology with arts and craft activities. The core goal of the activity is to attract and engage diverse student audiences with varying interest in STEM topics. While this appears to be successful, with examples of very effective student engagement, there are allied increases in communication, creativity, co-operation and effective group work.

In **Multistable Technologies and Pedagogy for Resilience: A Postphenomenological Case Study of Learning by 3D Printing** Nenad Pavel, Arild Berg and Birger Brevik (Oslo Metropolitan University, Norway) and Fausto Orsi Medola (Sao Paulo State University, Brazil) describe the disruptive influence of new technologies on the education environment and how we can teach new approaches to resilient learning, as well as nurture learners relations with the new technologies and societal changes which surround them. In the case study design students in Brazil used 3D printing to develop assistive technologies together with patients and therapists for a local rehabilitation centre. While the 3D printing allowed students and teachers much more freedom to prototype without all of the constraints of practical hand skills, and the technology soon became transparent to them, it did not produce a successful design outcome in all cases. The new technology proved disruptive to some, showing how students can struggle to adopt new technologies, while resilience emerged among all of the participants. As the introduction of technological advances accelerates, students will need to become more resilient in dealing with uncertainty and ambiguity, and learn to embrace this change rather than it causing them anxiety and threatening their wellbeing. It is certainly true that as educators we will need to consider ways that we can engender this resilient approach to learning and using new technologies.

Finally, this issue has a review of **Mentoring Design and Technology Teachers in the Secondary School: A practical guide** published by Routledge and reviewed by Stephanie Atkinson, University of Sunderland, UK. While this book has a definite UK focus the subject specific practical guidance should be equally relevant for those not based in the UK and who wish to effectively mentor and support the development of design and technology teachers.

We hope that you enjoy this issue of the journal.

Reflection
KEF, TEF, REF and all that: The current state of art & design higher education in the UK

Jake Kaner Nottingham Trent University, UK

International scholars may be rightly confused by the complexity of the UK university quality landscape. The UK has introduced a series of measures over the last decade to evaluate the quality of Higher Education (HE) knowledge exchange, teaching and research provision. This short piece reflects on the employment of assessment exercises for the art and design higher education sector in the UK.

As we have recently heard, the UK creative industries are the fastest growing sector in our economy. In 2018, the DCMS (Department for Digital, Culture, Media and Sport) sectors (digital, creative industries, cultural, sport and civil society) contributed £224.1bn with the creative industries providing a large chunk at £111.7bn (DCMS, 2018). Annually, Art and Design schools across the UK provide a constant flow of high-quality graduates into the creative economy, demonstrating that our educational provision is meeting requirements and our graduates are outperforming those from many other sectors.

The UK government's industrial strategy gave us all something to get hold of in terms of the relevance of art and design provision from undergraduate to post graduate research degrees. The creative industries continue to expand as predicted back in 2012, in that immense growth would occur in the sector between 2012 and 2022. This has held true to date. The past decade is expected to have seen over a million new jobs by 2022. As challenges occur in many work sectors in the UK, such as automation, the creative industries are proving to be resilient and see their workforces continue to expand. Many Art and Design Schools have collaborated across their institutions and introduced wider skill sets to their cohorts of students, such as digital design and coding. The skills portfolio of the art and design graduate is expanding to allows them to apply their skills effectively in a fast-changing world of work. We must continue to seek, teach and develop new agile skillsets that will maintain the value to employers and long term resilience of our graduates.

As economic measures are used to evaluate an art and design education, stakeholders for each student (including parents) are demanding a transparent understanding of the value of higher education. This goes beyond the cost of the degree to the individual student, but also seeks to articulate and measure the value of the complete university. What contribution does it make to the region, the UK economy and even the Global perspective? Attempts to provide answers and give value ratings for universities has partially been achieved through mechanisms such as the National Student Survey (NSS), Postgraduate Taught Experience Survey (PTES) and Postgraduate Research Experience Survey (PRES). For fuller accounts, assessment agencies have been constructed; the Research Excellence Framework (REF), the Teaching Excellence Framework (TEF) and now the Knowledge Exchange Framework (KEF).

Partly due to the three Excellence Frameworks (EFs) we are able to demonstrate that our sector does add significant value to the economy, to society and to wider cultural communities. The three EFs are affecting the work of art and design educators, bringing challenges and opportunities in abundance. No sooner has one set of data been translated into an understandable language then another set of terms and acronyms appear. This lexicon of meanings and measurements have and will continue to influence the lives of colleagues who teach and research in Art and Design across the UK in a number of ways. Navigating through this network of metrics and terminologies may appear joined up and fluent to the top-level architects who developed them, but translating this into values that the end user can judge to be worthwhile and worth investing in is a challenge.

All three EFs are designed to improve the visibility of our work in HE and demonstrate globally how much of a contribution we are making to 'UKPLC'. Institutions will benefit from this level of transparency so that consumers of education will know what to expect when they sign up to study or start a career in the academy. Or will they? As HE becomes a commodity for all stakeholders, do we understand the direction of travel, our responsibilities to ourselves and our users and where it will all land?

Strategies attempt to capture future visions of 3-5 years, 10 years and even 20 years. Reverse engineering is a tried and tested way of predicting the future and understanding what is needed to achieve ambitions and meet objectives, but does this really work with art and design education? How many strategies meet their consumer's needs, in the past, present and in the future? Should the student and academic expect to explore and take risks to further their understanding of the world and develop means to solve problems and future challenges for their stakeholders? The three EFs can show us how we are doing as institutions, positioning departments and all sorts of structured clusters of teachers, researchers, those engaged in knowledge exchange, but these mechanisms are not designed to further the development of individuals. It is the submission that counts, the unit, the body of work and the collective whole, not the person who has created the endeavour (the work).

Looking outwards from art and design, how is our sector performing against other sectors in the wider academy? Is it important to take account of this and is it appropriate to compare our work to other sets of values, such as science or other wider cognate areas? What will we gain from this and how will we develop ourselves as individuals and as a sector to ensure our future sustainability and cultural profit? Let's unpick the three EFs and see if this helps. I will not repeat the purpose of the three as these are given in the respective websites, REF: https://www.ref.ac.uk, TEF: https://www.officeforstudents.org.uk/advice-and-guidance/teaching/what-is-the-tef/ and KEF: https://re.ukri.org/knowledge-exchange/knowledge-exchange-framework/

KEF, the Knowledge Exchange Framework was due to commence in earnest in 2019/20 but this has been held back until next academic year, probably a wise decision taking into account the volume of work required to manage and administer the upcoming 2021 REF submission. The KEF will measure knowledge exchange and has organised a group or cluster of institutions by their likely ability, taking track record into account. So, universities find themselves competing with a whole new set of competitors. For some this is a relief, to be accepted into that particular club, for others it is as expected and of course for some that will be a challenge.

REF, the Research Excellence Framework, shortly to close its second census period on 31 July, 2020 has had earlier iterations of Research Assessment, with the RAE running from 1986 - 2008. The first REF (2014) which assessed research outputs, impact and environments between 2008 and 2013 changed the research landscape for art and design. We saw 84 institutions assessed and a significant amount of Quality Research income dispersed to the various institutions that achieved quality profiles (that is, included three and four start recognition for their research). The forthcoming REF (2021) has amended some of the rules governing the submissions and assessment of research. I expect that the following exercise (2027/28) will see further changes, some of which the sector will like, and others dislike.

TEF, the Teaching Excellence Framework has also had its controversies particularly of the resulting badges awarded to institutions; Gold, Silver and Bronze. Not all went as expected with some reputable universities achieving lower awards than anticipated. Some adjustments have been made and this occurs on a rolling basis and as new Higher Education Institutions are formed, they bring their assessments of teaching quality into the mix.

The various commissioned reviews of REF2014 caused some stirs in the Higher Education sector resulting in anomalies of an interim or transitional REF such as the ability of academics to move institution within the census period and 'port' outputs so that both employers for the individual in the census period could have some claim to outputs. What this has really shown is that the institution that sponsored the research owns the outputs not the individual. Submissions are now known as 'our work' not 'my work.' Interestingly, impact cannot be ported by academics as they move to a new post at another University. The most significant change has been the ability of universities to choose if they wish to submit all academic staff to REF or if they wish to produce a code of practice that describes their selection process, resulting in less academics being submitted to REF. As anticipated, submitting institutions are taking a variety of approaches in how they orchestrate this. All institutions that have submitted a Code of Practice have had to have it assessed by Research England, who manage the REF.

Can we anticipate that these three quality assessment processes will improve the provision of art and design higher education enabling us to improve what we do and better serve our stakeholders, allow the rest of the world to understand who we are and what we are capable of and finally maintain and improve our global standing? Of course, there are many other benefits of an art and design education, which includes contributions to lesser publicised audiences and marginal communities. It is not just the job at the end of a degree which is important, it is the development of the person throughout that journey which makes a wider contribution to society and develops the collective mind.

In some ways it is difficult to predict what the future of art and design will be because of KEF, TEF and REF. What we do know is that Higher Education has changed, and we can be sure it will not return. It will increase in its marketisation and continue to use measurements to be evaluated and judge itself. Metrics are here to stay, they bring value when used effectively, but the danger is that an educational focus on a measured set of imposed values can damage creativity and innovation through a lack of risk. This is even impacting design and technology at school level, for example the recently introduced English Baccalaureate (Ebacc) qualification may be guilty of this (https://www.gov.uk/government/publications/english-baccalaureate-ebacc/englishbaccalaureate-ebacc). A purpose of the three assessments in HE is to seek and find excellence and, once found, to promote it. This will have a number of dimensions; it will promote the sectors that participate, it will allow for greater access to our work of benefit to a range of stakeholders, it will offer attractive careers for school leavers.

How well do the three EFs do this in the UK and how much appetite for risk and innovation do they invite? Are they effective mechanisms for encouraging young teachers and researchers to join the sector and do these new recruits see opportunity for an exciting career where they can make a valuable contribution to society? Do other countries or regions use equivalent processes to measure the quality of knowledge exchange, teaching and research? It would be interesting to hear views from international colleagues on the effectiveness of such processes that are in place, or opinions on whether the introduction of such quality measures would benefit international art and design higher education institutions.

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Making the design process in design education explicit: two exploratory case studies

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Els Boshuizen, Open University, The Netherlands & University of Turku, Finland
Jeroen van Merriënboer, Maastricht University, The Netherlands
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Abstract
The aim of design education is that students learn to think and act like designers. However, the focus in the design studio is mainly on the design product, whereas the 'why and how' of the design process are barely addressed. A risk of learning by performing real-life tasks without addressing the skills involved, that is, without receiving appropriate support and guidance, is that learners are overwhelmed by the complexity of the tasks.

To make the design process explicit, a conceptual framework is developed in earlier research. This paper reports a first evaluation how articulation of basic designerly[1] skills with the help of a conceptual tool is perceived by students and teachers and whether it changes students' conceptions of the design process and their self-efficacy. In two exploratory case studies, questionnaires give insight. The first is a short intervention in which student's perception is measured. In the second case study the design process was addressed *in* the design studio. It measured changes in student's conceptions and self-efficacy. Also, insight is provided in teacher's perception of working with the framework.

The results of these exploratory studies indicate a positive effect. The teachers involved perceived the framework as a structuring factor during the tutoring sessions, for both teacher and students. Students did perceive explanation of the design process as being helpful. A change in students' design conceptions and an increase in self-efficacy is seen.

Key words
Design process, generic elements, framework, design education, architectural design.

Introduction
The aim of design education is that students learn to think and act like designers; they have to acquire the reasoning processes of professionals (Collins, Brown, & Holum, 1991; Van Merriënboer & Kirschner, 2018). For experienced professionals reasoning processes are not split up in separate steps. They constitute an undivided unity of automatic, unconscious actions based on common practice and routine, interspersed with conscious moments of reflection and exploration. For learners the complex, interwoven set of skills is (largely) unknown and unobservable. It has to be acquired by practicing while frequently doing 'whole'

[1] Cross, N.G. (2007). Designerly ways of knowing. Basel, Boston, Berlin: Birkhauser.

tasks (Van Merrienboer & Kester, 2008). To guide students in this 'journey in the unknown', it is helpful to address the design process explicitly.

However, in the architectural design studio[2] students seem to learn mostly by practicing design tasks without explicit articulation of the actions and skills involved. Research in architectural design education (Van Dooren et al., 2019) has shown that tutoring appears to be primarily a matter of discussion on the level of the design product at hand. Teachers talk with students about all kinds of aspects involved in the design product in relatively detailed terms: such as the position of rooms, the form of the building, the view and the composition of the facade, and all other kind of aspects. If they refer to the design process, they do so almost solely as a kind of side remarks or footnotes. The 'how and why' of the basic design process are barely addressed.

A risk of learning by performing real-life tasks without addressing the skills involved, that is, without giving appropriate support and guidance, is that learners are overwhelmed by the complexity of the tasks (Van Merriënboer & Kirschner, 2018, Sweller, Van Merrienboer & Paas, 2019). Students are asked to perform skills, that are still unknown to them. In the context of a working memory with limited capacity and a lack of adequate cognitive schemas and conceptions in their long-term memory, students tend to focus mainly on the specific design project at hand without a learning process taking place. Articulation and instruction of the professional reasoning processes, more in specifically the design process, will help students to develop effective conceptions.

Reasons for barely addressing the design process in the design studio, may be the lack of a commonly shared vocabulary and lay person conceptions on design education (Van Dooren et al., 2019). Teachers, being experts performing their skills for a large part implicit, talk with students in the same way they talk with colleagues in the design office and in the way they remember from their own education as a student. They are not used to talk about the design process and if they refer to it, they use their personal notions. Not being trained as teachers, they also seem to think that students (only) learn by discovering the designerly skills themselves (Van Dooren et al., 2019). Guidance in the form of leading questions and well-designed learning tasks regarding the skills that students are supposed to develop does not seem desirable in this view.

To be able to make the design process explicit and to have a common base for communication, a generic framework has been developed (Van Dooren et al., 2014). Five elements have been distinguished to explain the design process in relation to all kinds of design situations at hand, and to guide and train students in the development of design skills. These two main goals may include other goals, such as the comparison of personal design approaches and the articulation of the design processes in the context of teamwork.

This paper presents the results of two exploratory case studies, in which the framework is used to make the design process explicit and to guide and train students in specific essential

[2] The research in this paper focuses on architectural design, but for reasons of readability, regularly the shorter notions 'designing' and 'design process' are used. At the same time, the results of focusing more on the design process in design education and the generic elements may be recognizable for other design disciplines as well (Van Dooren et al., 2014).

design skills. The aim of the *first case study* is to investigate how first and third year Bachelor students perceived the articulation of the design process. The *second case study* gives insight in the results of working with the framework in two Master design studios. How did the teachers perceive the use of the framework in the tutorials and did students' conceptions of the design process and their self-efficacy change as a result of using the framework?

In the remainder of this introductory section, information about (the relation between) students' self-efficacy, their design conceptions and the way teachers articulate the design process will be given. Then, the framework is briefly introduced. The section ends with the main research question, the sub-questions and an introduction on the research method. The following two sections each present and discuss an exploratory case study. Finally, overall conclusions are drawn and discussed.

Self-efficacy and design-process conceptions

Students' self-efficacy, their design process conceptions and the way in which teachers make the design reasoning processes explicit and help students to acquire adequate design skills are related to each other.

The design process conceptions are the mental models and cognitive strategies, which describe how to perform tasks and how to reason. There may be large differences between effective sophisticated conceptions of professional designers and intuitive or lay person conceptions used by novices (Van Merriënboer and Kirschner, 2018). Students and lay persons tend to consider designing as a process of solving 'the problem', posed by conditions and criteria, presented by the client, site and program analysis. Observing the typical behaviour of novice design students and comparing it with their conceptual drawings of the design process, made by these students, Newstetter and McCracken (2001) concluded that the drawings were prophetic for the design behaviour of students. The design process was mainly represented in two ways: in linear flow charts and as a creative process, with an emphasis on brainstorming, intuition and imagination. These conceptions could be recognised in the behaviour characteristics they observed: (1) coming up with good ideas without evaluation, (2) coming up with solely one idea without considering alternatives, (3) working in a linear, serial process without iteration, (4) working on the idea and the component level without moving between these levels, and (5) ignoring constraints and context (environment and user). The sophisticated conceptions of professional designers include designing as an ill-defined, open-ended, complex, personal and culturally influenced process. The process unfolds in a process of experimentation. Conditions and criteria are discovered during the process of exploring and reflection. Designing is a matter of coming up with inferences and profound testing of possible solutions (Cross, 2007; Lawson, 2006; Lawson & Dorst, 2009; Schön, 1983, 1985, 1987). If teachers show and articulate their sophisticated design-process conceptions, students' ability to perform the design process may increase and their self-efficacy may rise.

Self-efficacy, the perceived belief in the personal ability to perform, is caused by and affects different cognitive, motivational and affective processes. Sources of self-efficacy are mastery experiences, experiences provided by social models, social persuasion and the reduction of stress reactions (Bandura, 1994). In principle, if students are able to master challenging tasks, not too easy, but still realistic in relation to their prior knowledge and experience, their self-efficacy will increase. Their ability to perform challenging tasks will increase and their stress level may decrease. Main teaching issues to increase the ability to master challenging tasks are the behaviour and articulated way of thinking of the teachers and the way in which they help students acquire skills that enable them to deal with new tasks.

A framework for design education

In the past decades, research has been conducted on the reasoning processes of design experts. Researchers have used different terms to describe the different basic skills, such as conjecture and analysis (Hillier, Musgrove & O'Sullivan, 1972); primary generator (Darke, 1979); imposition of an order, naming and framing, reflection-in-action, conducting experiments, and a web of moves (Schön, 1983, 1985, 1987); a co-evolution of solution and problem spaces (Lawson, 2006; Cross, 2007; Lawson & Dorst, 2009), and ideation and evaluation (Goldschmidt, 2014). These terms are regularly overlapping each other.

To help teachers and students discuss the design process, an overview is needed which is relatively simple to remember and easily to use. Therefore, the body of knowledge is brought back to as few elements as possible, five basic design skills present in any design process. The elements are interwoven with each other. There is no fixed step-by-step sequence; the emphasis on the elements depends upon the kind of project, the designer and the design discipline. The five elements are certainly not meant as a prescription or recipe for design, they are only meant to articulate the 'designerly' reasoning processes and to help in designing adequate design courses, to guide and train students in the main design skills.

For each of the elements (see Figure1) a short description is given:

1. *Experimenting* is a process of *exploring and reflecting.* Exploring refers to a process of being open and alert, coming up with alternative options in a rational and associative manner. Reflection refers to the process of testing, of analysing and evaluating the possible solutions, looking for (un)intended consequences of the provisional solutions and looking for the option that best fits the design situation at hand. Experimentation is studying different options, in a fractal-like process of diverging and converging.

2. *Guiding theme* or *quality* stands for the 'emergence' or imposition of a focus, an inspiring direction, something to hold on to in an almost endless field of possibilities and to help in creating coherence and significance in the design result. The guiding theme is the personal 'answer' of the designer, influenced by culture and profession. The qualities develop during the design process, from vague and abstract to a concrete elaborated solution fitting the situation at hand.

3. *Domains* consist of all *aspects and scale levels* designers have to address in the design result, such as space, material, function, the direct context of the site, and a broader socio-cultural context. Designers have to make statements and choices and they have to deal with a lot of knowledge and information - such as criteria, rules, preferences and cultural habits - in and across the domains. Aspects influence each other, choices in one domain can be made with knowledge about other domains.

4. The *frame of references* is the common professional and personal *library of knowledge* and experience in the minds of designers, consisting of ideas and qualities and abstract and proven rules of thumb, principles and patterns. In these 'knowledge chunks' different domains come together (for example in a spatial type structural or circulation aspects are already embedded). Consciously or unconsciously, designers explore and test these 'knowledge chunks'; they use, reject and transform them in the situation at hand.

5. *Laboratory* is the (visual) language designers use to experiment. The most important physical "designerly language" is *sketching and modelling.* The visual functions as an extended working memory, complementary to the language of words and notions. With the help of different visual means, the process of "designerly" thinking, of exploring and reflecting on options and discovering new insights, unfolds.

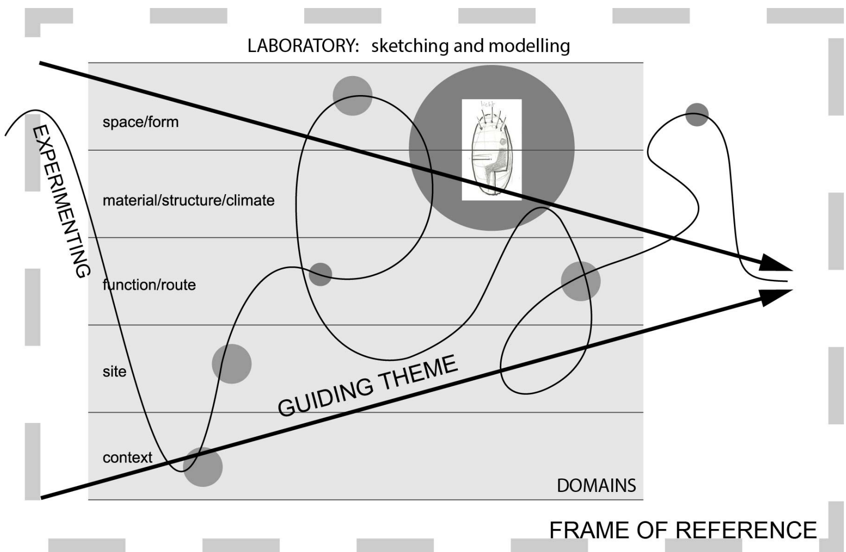


Figure 1. The five generic elements in the design process: (1) experimenting, (2) guiding theme, (3) domains, (4) frame of reference and (5) laboratory (van Dooren et al., 2014)

Questions and method

In the research presented here, the main question is how articulation of basic designerly[3] skills with the help of a conceptual tool is perceived by students and teachers and if it changes students' conceptions of the design process and their self-efficacy.

To answer the main question, four sub questions will be answered in two case studies (Harland, 2014; Burke Johnson, Onwuegbuzie & Turner, 2007). The *first case study* explored the perception of students: (1) how did first and third year Bachelor students perceive the value of the framework as a conceptual instrument to gain understanding of the design process? The *second case study* focused on students and teachers in two master design studios. This study explored the change in students' conceptions and self-efficacy: (2) Did first

[3] Cross, N.G. (2007). Designerly ways of knowing. Basel, Boston, Berlin: Birkhauser.

year Master students acquire more sophisticated conceptions? and (3) Did addressing the design process increase their self-efficacy? Finally, the teachers involved were questioned about their perceptions: (4) Do teachers perceive the framework as a supportive tool to make the design process explicit, for themselves and for their students?

Both case studies include each an intervention, a questionnaire and statistical analysis. An overview is given in Fig. 2.

In the *first case study* the perception of Bachelor students was measured. It is expected that students' conceptions and self-efficacy may change if teachers address the design process intensively, more specific during a longer period in direct relation to the design process at hand. Therefore, the *second case* study included a more profound test of the framework in the design studio. Two relatively small groups of students were involved in the intervention: almost without and with a few years design experience. Also the teachers involved were asked whether the framework was perceived as useful. In addition to the research, informal anecdotal information is given from students involved in the master studios.

	first case study: Bachelor
content	lecture, text and reflection
participants	380 first year + 240 third year BSc students
perception	survey + analysis value of making design process explicit and reflection on personal design process

	second case study: Master design studios
content	lectures, text and reflection + tutorials and training
participants	7 academy, 8 university MSc students, respectively without and with design experience + 3 teachers
perception teachers	survey: value framework for tutoring and for students
conceptions students	survey + analysis: five notions, a visual representation and imagine a house
self-efficacy students	survey + analysis: statements concerning understanding, trust,…

Figure 2. Overview of the two case studies.

Case study 1: students' perception (first sub question)

Participants and setting

All architectural students involved participated in a first or a third year 'academic skill' course in the Spring semester of 2017. The students followed a BSc Architecture study at a Dutch university. Almost all of them came directly from high school in the Netherlands.

The first-year students (N=380) fulfilled a 'one-day' assignment, a short reflection written on the day of the lecture without further guidance. The third-year students (N=240) worked on a 'two-weeks' assignment; they were guided by 20 teachers, selected to teach research and writing and having different teaching experience in general and in these courses specifically.

The information for students and teachers consisted of an English text about the five generic elements (Van Dooren et al., 2014) and one lecture, which provided a short overview of the generic elements (by the first author). On the basis of the framework, students were asked to write a reflection on their personal design process in a parallel running design project.

The first year students' response rate was 29%, the third year students' response rate was 30%.

Material, procedure and analysis

Questionnaires concerning the first sub question were distributed in September 2017. Figure 3 shows the questions which focused on reflection on the personal design process (1.1), and more specifically with the help of the framework (1.2 and 1.3), the value of making the design process explicit in a text and lecture (1.5), and having knowledge of the design process (1.6). The main goal was to get information on students' perception. But because there seemed to be a relative large difference between the assessments given by the first and third year students, it was tested with the Mann-Whitney U test for two independent samples.

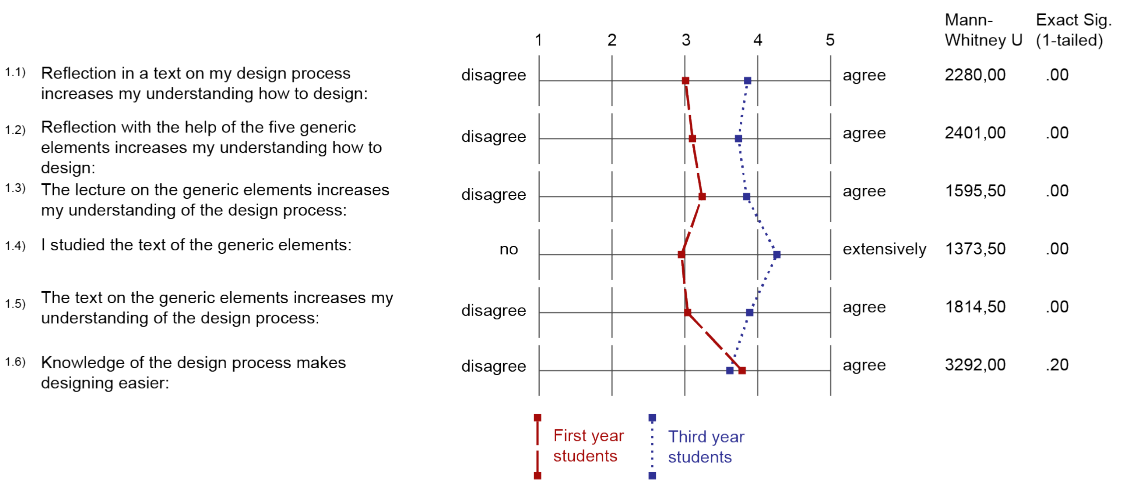


Figure 3. students' perception of making the design process explicit and Mann-Whitney U test for differences in assessment by the first / third year students

Results

Figure 2 shows the results. Five out of the six statements have been assessed significantly different by the first year and third year students ($p < .001$). Addressing the design process (in text, lecture and reflection) is perceived neutral by first year students and significantly more positive by third year students. Both groups are equally positive on ‘knowledge makes the design process easier’.

Discussion

Making the design process explicit with the framework of the five generic elements as a conceptual tool (first sub-question) has been perceived neutral to positive.

There may be several causes for the distinction in outcomes between the first year and third year students. The most obvious reasons may be the difference in duration of the assignment (one day versus two weeks) and the difference in design experience. Third year students may be more in need of getting to grips with the design process and they had more time to study than first year students.

The *first case study* investigated the perceptions of making the design process explicit by a relatively short ‘study and reflection’ task in a separate course, parallel to the design studio. However, designing is learned in the design studio, during the whole design project. Therefore, the data collection for *the second case study* takes place in the design studio: the design process is made explicit in direct relation to the successive preliminary design products of the students.

Case study 2: teacher perceptions and students’ change in conceptions and self-efficacy (second, third and fourth sub question)

Participants

All students involved studied architecture and participated in one of two Master design studios in the Fall semester of 2017. The studios were given in two different Dutch design schools, an academy and a university. The *Academy Project* is a mandatory MSc 1 studio. Eight students had started their Master with no or relative little design experience. They had different backgrounds: primarily building sciences and in a few cases civil engineering or art. This MSc 1 is the first studio in a four year part time study, in which students always work in design offices parallel to the design studios. The *University Project* is an elective MSc 2 studio, part of a two year full time MSc Architecture. Six out of seven students already completed a full time three year architectural design BSc at the same university, one student completed a building engineering BSc background. This elective MSc 2 included a ten week long apprenticeship as assistant-teacher in a first year design studio for Bachelor students. The language spoken in both the academy and university project was Dutch.
The teaching staff consisted of four teachers, including the first author. The other three were selected because they had a more than average interest in being more explicit about the design process. The teachers worked partly individually, partly in couples in the design

studios. They differed in experience in teaching in general and specifically in supervising these projects.

Setting

In the Academy Project the students had to do one design assignment and in the University Project students had to do three relatively short design tasks. Goal of both design studios was to learn to (1) experiment by sketching and modelling as the basic 'designerly' skill, (2) work with a guiding theme or qualities, (3) see the relations between the different architectural aspects or domains, and (4) recognize (spatial) patterns in reference projects and explore them in a project at hand (frame of references).

The framework was addressed in several ways. First, information on the generic elements was given in a text (Van Dooren et al., 2014) and in lectures, given by the first author in the first weeks of the projects. After an overview lecture, the elements were discussed more in depth in three other lectures. Secondly, during the design tutorials the teachers referred to and explained the basic 'designerly' skills as best as possible in relation to the design situation at hand. Table 1 shows examples of how the design process was addressed in the tutorial dialogues. Both, leading questions and learning tasks, were used during the individual dialogues and during group tutorials. Thirdly, all students had to present their design process on a poster and write a reflection about it, in the order of the elements.

Table 1. Examples of leading questions and learning tasks referring to generic elements, referred to in direct relation to the design at hand.

generic element	examples of leading questions, asked by teachers	examples of learning tasks, instructions given by teachers
Experiment	what happens if….? / which experiments did you have done? / what implications did you discover? / which one do you prefer? / which experiments should be done next?	come up with few different options / looking for the similarities and differences / testing an experiment in other domains
Guiding theme	what kind of identity or quality do you want to achieve? / is this […] the meaning you want to give the design? / which means are related to the chosen quality?	come up with different qualities for this particular design situation / come up with alternative options and architectural means to express the chosen quality'
Domains	what does this decision (e.g. a spatial order) mean for other aspects (e.g. the structure)? / in which domains(s) do you have or wish to do experiments as a next step? / what does the theme or identity mean for this aspect?'	look for implications of a choice in one domain in other domains / study the architectural means in the different domains to express the chosen theme

Frame of reference	what happens if you do it like [...] ? / which projects do you like and which values or qualities do they express, in specific for your design? / what does this [... e.g. spatial] pattern mean for the other aspects?	come up with the patterns in these projects / experiment in the design situation at hand with these patterns
Laboratory	how do you test these possible solutions, in a sketch, model,...? / which visual mean do you need? / what did you discover by making a model?	make an abstraction / study the possible options by making different sketches and models / explore this option in plan, section and perspective

Material and procedure

Table 2 shows the questions concerning the change in students' conceptions (second sub question), the change in students' self-efficacy (third sub question) and the teachers' perceptions (fourth sub question). To gain insight in the change in students' conceptions and self-efficacy, a questionnaire was handed out before, directly after, and 2-4 months after the project (pre, post and delayed post). The change in conception of the design process, was measured in three questions. The change in self-efficacy was measured with a set of 8 statements that had to be scored on a 4-point scale (completely false / barely true / somewhat true / completely true). To gain insight into the experiences of the three teachers involved (apart from the first author), they answered three open questions after the design studio.

Table 2. questionnaires in reference to addressing the design process in the design studio: teachers' perception and students' change in conceptions and self-efficacy (pre, post and delayed post).

Subject		Questions
students' conceptions (third sub question)	Q 1	What are the first five notions you think of regarding the design project?
	Q 2	Make a visual representation of the design process with the help of the words from the previous question.
	Q 3	Imagine, you get the assignment to design a free standing house. Explain in short how you would approach this task (max. 100 words).

students' self-efficacy (fourth sub question)	 s 1 s 2 s 3 s 4 s 5 s 6 s 7 s 8	To what extent do you agree or disagree with the following statements at this moment: I have enough understanding of the design process to be able to design. I trust myself that to effectively approach unexpected events while designing. I have enough insight and skills to integrate different aspects in a design. While designing, I always see multiple solutions. When I get stuck in the design process, I know in most cases what to do. I know I'm able to apply generic design principles and basic skills. I know that I'm able to become an excellent designer. Although it can be difficult, I have fun in designing.
teachers' perceptions (second sub question)	q 1	Does the framework help in tutoring students? If so, how / why?
	q 2	Do you have the impression that it helps students? If so, how? (if possible with examples of students)
	q 3	Other remarks?

Analysis

The process of coding, counting and analysis of *students' conceptions* is done by two researchers. The codes were defined, based on the five elements and study of the data. The final decisions were taken by the main researcher (first author).

Regarding the *first five notions you think of regarding the design project* (student's perception Q 1) eight codes were distinguished. Two codes for separate aspects and actions (D1, space, form, function, and E1, exploring, deciding) and five codes for the elements as comprehensive notion: (D2, domains; E2, experimentation; G, guiding theme; R, frame of reference; L, laboratory) and one code for all other notions, regularly more personal perceptions (P; stress, complex). The differences between the codes were tested with the Cochran Q test for k-related samples with a binary variable. Before the test the scores were transformed into binary variables (0 - 1 / item named or not named).

In reference to the *visual representations of the design process* (students' perception Q 2), five codes were distinguished, gradually increasing in complexity: (1) linear steps, (2) linear steps with one feedback loop or parallel lines in one step, (3) steps with several loops or parallel lines, (4) zigzag, parallel lines, network like, and (5) complex combinations of zigzag, parallel lines, including guiding theme lines.

With respect to *the descriptions given imagining a real situation* (students' perception Q 3), the stories were analysed in idea units. Three codes were distinguished: (a) the number of elements mentioned in combination in one idea-unit, (b) the process as elaboration or experimentation, and (c) the emphasis on preconditions, including client, site analysis and program.

The internal consistency of the eight *self-efficacy* statements (s1-s8) is tested with Cronbach's Alpha coefficient. A reliable scale is shown for the second and third measurement (Cronbach's Alpha > 0.8); it was relatively low but still acceptable for the first measurement (Cronbach's Alpha = 0.67).

Results

Change in students' conceptions (second sub question)

The data collected from the questionnaires provide insight into the change in students' conceptions of the design process, seen from three different perspectives: the first five notions you think of regarding the design project (Q1), visualisation of the design process (Q2), and the imagination of a real situation (Q3).
In Table 3 *the notions named* (Q1) are presented in relation to the elements of the framework. Specifically, four groups of notions show a significantly different distribution of the measurements pre and post the project ($p < .05$): a decrease in separate aspects, such as space, function, site (D1) and separate actions such as exploring and investigation (E2), and an increase in the more comprehensive notions domains (D2) and frame of references (R).

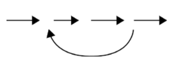
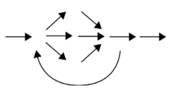
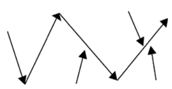
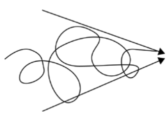
Table 3. Numbers of notions named by students per measurement reflecting their conceptions on the design process and significant results on Cochran's Q tests.

	CODE	NOTIONS	Pre	Post	Delayed post	***Q***	***df***	***p-value***
DOMAINS	**D1**	partial notions, separate aspects, such as space, user, material, context, site, form,…	24	8	14	8	2	.02
	D2	comprehensive description, such as domains or aspects	0	7	7	9,8	2	.01
EXPERIMENT	**E1**	partial notions, specific actions, such as develop, investigate, discover, (connecting) ideas, study, analyzing, di/converging, reflection, iterate, compare, (dis)advantages,	15	7	6	*3,5*	*2*	*.27*

	E2	comprehensive notions, such as experimenting.	1	13	9	18,67	2	.00
GUIDING THEME	**G**	comprehensive notions, such as concept, vision, direction, (guiding) theme	6	9	12	*4,91*	*2*	.10
REFERENCES	**R**	comprehensive notions, such as (frame of) references, case studies,	2	9	10	11,4	2	.00
LABORATORY	**L**	comprehensive notions, such as sketching, modelling, drawing, laboratory	9	9	6	*0,75*	*2*	*,90*
PERSONAL GENERAL, PERCEPTION	**P**	observing, input, collaboration, creative, logic, design, learning, presentation, flexible, divers, creative, designing, fail, critical and honest, keep positive, stress	18	12	11	*1,56*	*2*	*.59*

Table 4 shows the *change in the visualisation of the design process* (Q2). A shift can be seen in the number of students from naming more simple, step-by-step visualisations before the project towards criss-cross and complex visualisations after the project. The Chi-square test shows a significantly different distribution of the measurements of how students visualise the design process (chi-square=15,85, df=8, p < .05).

Table 4. Visualisations of the design process: a shift in the number of students from naming more simple towards more complex visualisations.

abstraction of patterns	→ → → →				
	1. Linear steps	**2. Steps / feedback loop / parallel lines**	**3. Steps / more loops +/parallel lines**	**4. zigzag/ parallel lines/ network like**	**5. zigzag/ parallel lines/ network like/ incl.**

					guiding lines	complex
pre	2	5	4	2	2
post	0	2	2	5	6
delayed post	0	0	3	3	9

Figure 4 shows some examples of student visualisations. All four selected students start with a more linear sequence. The academy students A2 and A3 show in their visualisations 'having ideas' as parallel actions in one step, which then are worked out in the next steps. The visualisation of university student U6 is the most linear one, U5 is the most complex one. Post and delayed post the project almost all visualisations show higher complexity. The visualisation of student A2 shows delayed post a more criss-cross symbol. In the visualisations of student A3 the linear sequence is still there but now in an iterative loop. The visualisations of U5 and U6 are more complex and criss-cross and show more resemblance to the framework: student U6 refers almost literally and student U5 comes up with a personal interpretation of the framework.

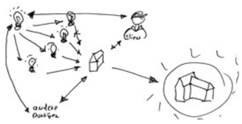
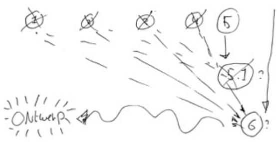
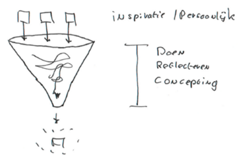
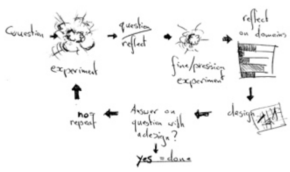
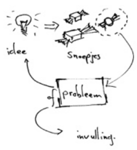
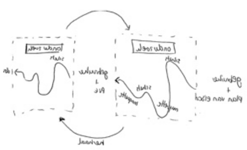
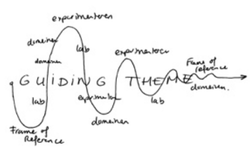
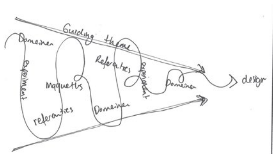
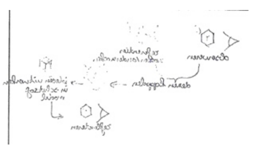
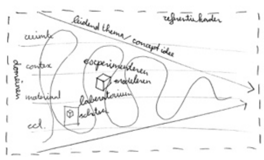
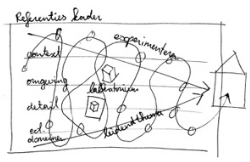
	Pre	**Post**	**Delayed post**
A2			
A3			
U5			
U6			

Figure 4. Examples of visualisations of the design process of four students, measured pre, post, and delayed post (Q2).

In reference to *the imagination of a real situation* pre, post and delayed post design studio (Q3), the stories seem to change in conception from simple towards more complex, 'from problem solving towards designing'. Table 5 shows examples of the same students as in Figure 3 (Q2). Before the project the design seems to be directed by client / program and site analysis. After the project client / program and site analysis are still important, but other actions are also mentioned such as essence, experimenting and alternatives (student A2). A second parallel tendency concerns the notion elaboration. Before the project the design process seems to be mostly a matter of elaboration (of one or more ideas), after the project refining is still mentioned but more in combination with developing a theme and testing on domains (student A3). And finally, directly after the project the idea units include more actions and skills in direct relation to each other. Student U5, for example, says: *"At the hand of references and personal ideas slowly a 'guiding theme' will emerge, or at least the start of it"*. And U6: "*Also I should look into houses of buildings in reference to my guiding theme. These might be inspiration to experiment further in the different domains."*

Table 5. Examples of descriptions imagining a real situation (question 3).

Student	Pre	Post	Delayed post
A2	"Firstly discussing with the client, based on the 'right' questions, to collect starting points. Then looking over site, context, orientation and so on. // Then discussion about the design with the client for remarks. When needed modify."	"Discussion with client to achieve 'true wishes'. //Coming up with the essence. Followed by a frame to direct the process.// Experimenting with aspects such as form, site, material and context. // Then showing alternatives to client to reflect and develop."	"Discussion with the client, to get to know him (personality, character, interests, preferences).// From here trying to come up with a guiding theme, with conditions connected to it. // Next all information trying out in different sketches and models. // Reflection together with the client."
A3	"Check my limitations: budget, environment, size. Think about primary goal(s) and list them. Think about secondary goal(s) and list them. // Sketch a number of designs. Ponder which feels to fit the	"Investigate the site. What are the values. How can I use them? // Start sketching designs. See what works with your site and "ambition". // Develop a guiding theme.//	"Visit the site. What kind of experience I want? // Experimenting. // Some elaborate, reflect on domains and elements. // Repeating this until time ends or project is finished."

	goals the best (could be multiple). // Refine the design to make it practical while maintaining the essence. Finished.”	Find references which work for your design. // Start testing your design on the domains and reflect. // Refine your design or alter your design accordingly. // Repeat till finished/ out of time.”	
B5	“I should start with an investigation of the site […] requirements users, looking at their living style […] From this investigation you achieve the most important design themes or improvements, together the starting points. // With these starting points, you sketch and model. // First on larger scale, but also ideas on a smaller scale can be imported. // In between you look if the provisional design fits the user. // Probably you have to make more versions. Iteration till a fitting design.”	“I should start with exploring qualities in the site and task to come up with a guiding theme. // Then experimenting by sketching. Firstly, testing functionality and spatiality, e.g. in different plans. // The choice is made with the guiding theme at hand: does it fit? //References may help in generating new ideas, to experiment further. // Working in different scales, making variants, making provisional choices working in a different domain. Coming back on previous decisions. // Through the whole process the guiding theme serves as a kind of test frame, to come up with a coherent whole.”	“I would start with looking into the domains: what spatial area is needed. // At the hand of references and personal ideas slowly a ‘guiding theme’ will emerge, or at least the start of it. // Next experimenting will provide alternatives in the five domains. // The experiments fitting the theme, atmosphere and the requirements are feasible to do further experiments. // This proceeds until the point that design and theme are a whole.”

B6	"Starting with investigation of the site, what kind of existing materials, culture, and so on. For whom, what are the requirements or interests. // Next to that searching for other references for inspiration. /Then, mostly the first sketches will unfold. // If I get stuck, I often make a small model or repeat investigation. The sketch or model I reflect to the self-imposed requirements or starting points."	"I would start with coming up with the kind of house I want to make: atmosphere, impact,… next to that I should look for references, which direction I want to go (guiding theme). // Then I would start with sketching and making a lot of alternatives, look if they fit in the guiding theme. // Then elaborating through the different domains, until a consistent, good elaborated design is developed."	"First I should investigate the environment and the context of the site. // From here a guiding theme may rise; or a fascination could be for me the guiding theme, which I will use to experiment. // Also I should look into houses of buildings in reference to my guiding theme. These might be inspiration to experiment further in the different domains. // Finally, testing in reference to the theme a final design is worked out."

This last effect, the combinations of design elements, is also presented in Table 6. The overall Chi-square test over the three measurement moments shows a significant difference in combined elements just after the studio (chi-square= 16.77, df=3, $p < .01$). Also the decrease in combined elements from the second to the third measurement moment is significant (chi-square=9,25, df=3, $p < .05$). So the increase in the combined elements is only present just after the studio and does not last.

Table 6. Number of idea units with a combination of elements mentioned imagining a real situation per measurement (Q3).

	Pre	Post	Delayed post
1 element	42	25	41
2 element	13	30	16
3 element	0	5	4
4 element	0	1	0

Changes in students' self-efficacy (third sub question)
After the project the self-efficacy of the students (see Figure 5) has significantly increased and the effect remains till at least 2-4 months after the project. ANOVA with Repeated Measures

shows significant differences between the average self-efficacy scores (F = 21.54; df = 2.13; p < .01). Paired t-tests showed significant differences between the first and the second measurement (t=-4.79, df=14, p<.01) and between the first and the third measurement (t=-6.72, df=14, p < .01). It is interesting to see that self-efficacy did not drop after 2-4 months (see Figure 4).

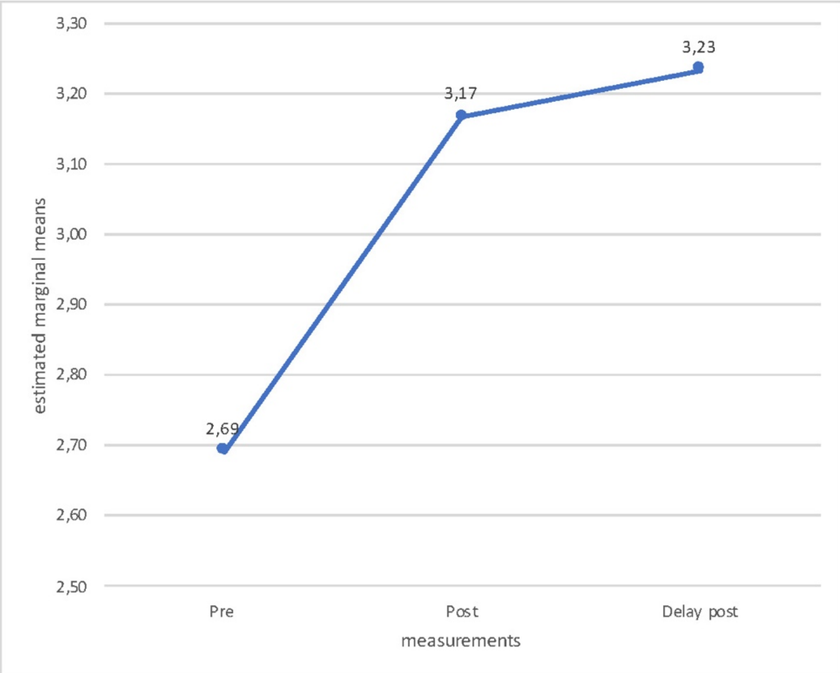


Figure 5. Increase in self-efficacy students pre, post and delayed post project

Teachers' perceptions of using the framework (fourth sub question)
Each three teachers involved (apart from the first author) perceived the framework elements as a structuring factor during the tutoring sessions, both for teachers and students. Teacher 2 compared the framework with a map: the discussion with the student improves if you have an overview of all areas and know which area is the discussion topic at a particular moment.

Teacher 1 mentions that it is almost a list you have in mind, with the kind of things which may be discussed with the student. When a student gets stuck, he literally goes over the list together with the student to show how you may act in situations like these. Teacher 3 asserts that it helps in formulating concrete tasks for students, such as experimentation. When a student gets stuck, he is more able to see possible reasons, such as not enough references, no clear theme, or no experimentation.
The teachers had the impression that the framework directly helped the students to decrease anxiety and uncertainty and to get to grips with the design process. Students' pleasure and understanding seemed to increase and they felt that they were allowed to make mistakes.

As extra remark teacher 1 mentioned that it helped when working with a student on a design you do not like as a teacher. He continues: *"I'm used to teachers with a judging attitude, from their opinion about right or wrong, attractive or unattractive. This method gets around this.*

That is clever, because as a human being you tend to the 'right or wrong' attitude very easily." Teacher 3 mentioned that his personal fun in designing and design tutoring has increased.

Spontaneous student' remarks

Not only the results of the questionnaires, also spontaneous remarks made by the students confirm the assumption of teachers that the framework may be helpful for students. In the University project, some of the students used a representation of the generic framework more or less literally. Questioned why, they concluded that the scheme was very helpful, therefore they worked with it the whole studio period. And one of the students participating in the Academy Project reported similarly in an email. He wrote that he started with the wish to be an architect, but almost without understanding of what designing meant. His first design studio in the Academy project was a struggle, also with the scheme and text. After the first design studio during the next two design studios, he related most of his actions to the scheme to understand the process. In the fourth project the scheme was solely implicit somewhere at the back of his mind and his understanding of the design process had increased, which was also illustrated by his grades (from sufficient to good).

Discussion

The second case study indicates positive results. Regarding the *conceptions of students* (second sub-question) we see to a certain extent a move from layperson conceptions towards sophisticated conceptions of the design process. The layperson conceptions consist of (1) a linear design process, frequently with a feedback loop, (2) having ideas (without testing) or having one idea and elaboration, (3) the client as a source of feedback, and preconditions in general such as brief and site analysis as source for solutions, and (4) a relatively high number of separate aspects, such as space, site, form, and partial notions such as investigation. Students may see the design process as coming up with ideas as a kind of solutions, as 'logical' implications of the design task and its conditions, more specific of 'what the client wants'. In this conception the designer seems to solve the problem, put forward by the client. The more sophisticated conceptions consist of (1) a zigzagging, criss-cross, and parallel process, (2) more comprehensive and inclusive terms, such as experimentation, guiding theme (concept, vision), and frame of reference, and (3) naming the design actions and skills more often in relation to each other. The discussion with the client is still there, but students may see designing more as exploring and testing alternatives, working parallel and across in the diverse domains, and working with overall qualities or guiding themes.

Regarding *students' self-efficacy* (third sub-question), on average *an increase is shown* after the design studio. Studying the design process and having more sophisticated conceptions of the design process may be related to the believe in being able to design.

Finally, the teachers involved in the design studios *perceived* working with the framework (fourth sub-question) as a structuring factor, which helps teacher and students to gain an overview and helps in cases of getting stuck. It may help in making the tutoring less dependent on personal preferences of the teacher. The teachers' perception that the framework may be helpful for students seems to run parallel with the changes in students' conceptions and self-efficacy.

General Discussion

The results of the two case studies indicate positive effects of making the design process explicit. At least a part of the students did perceive articulation of the design process as being helpful. For the teachers involved the framework works as a structuring tool. Their perception that it helps students, seems to be confirmed by the change in students' design conceptions and their increase in self-efficacy.

However, the positive results presented here should be taken with caution.
Obviously, there is no guarantee that using the framework terms more often after than before the project will lead to better understanding and improvement of design skills. Secondly, solely based on the second case study, it cannot be concluded that the moves in conceptions are more different than they might have been in a 'normal' product-oriented educational approach. Even though the fact that more or less the same kind of lay person conceptions were seen at the start of both the Academy and the University Project, indicates that there was no difference in conceptions between less and more experienced design students. Thirdly, the increase in self-efficacy may also have other causes, such as a positive encouraging studio environment. And finally, conclusions can be solely tentative because of the limited scale of the case studies.

Only a full experiment with a larger number of students, with control groups and during a longer period of time may provide more robust evidence for the effects of making the design process explicit. In a large-scale experiment, especially during a longer period, it is not only expected that students' self-efficacy increases and student's conceptions of the design process become more sophisticated, but also students' skills may increase and become more adequate and effective.

Yet, the positive results run parallel with the positive informal reactions of participating students and they are in line with other research. Kirschner, Sweller and Clark (2006) conclude that controlled studies support strong instructional guidance for the learning of complex skills. The results of the second case-study show the same kind of lay person conceptions of novice design students, as Newstetter and McCracken (2001) exposed. With only one exception: students do not seem to ignore the constraints and context, they seem to expect that (profound) knowledge of preconditions (site, brief, client) will lead 'automatically' to a design solution.

Framework

Making the design process explicit with the framework did work well in practice. In principle, the choice for the five elements may to a certain extent always remain a matter of discussion. However, the elements seem to be 'resilient'. They fulfil the requirements of being (1) generic, basic skills of the design process, (2) the main skills to be learned by novices, and (3) relatively clear and easy to remember (Van Dooren et al., 2014). They are key items in the design process, distinguishable and providing an overview for teacher and student.

The elements also include a 'world' of notions and mutual relations, related to the nuanced and rich reality of designing, which still has to be discovered, developed and worked out. In the second case study, we experienced on a small scale that structuring learning tasks accordingly to the elements, may lead to learning to design in a 'natural' way. Especially in the first year(s) of the design study, providing experience in the form of adequate, specified learning tasks may help students to overcome the paradox formulated by Schön (1987): although students do not and cannot understand what designing means, neither can recognise what they see, they have to learn by doing it. Developing the framework more in detail may help in the set-up of the curriculum and the design studios. It should provide learning tasks that are interwoven with the design process. It may also help to 'translate' more general notions such as investigation and creativity in more concrete and specified actions and put all kind of notions such as analysis in a broader perspective.

To conclude: design education, in which the design process is made explicit with the framework may have positive results. A richer understanding of the design process and a better specified training of the students may help students to learn 'the unknown'. Students may experiment more often, taking informed decisions and working with professional patterns. They may articulate, develop and explore qualities more consciously and they their ability to distinguish and compare different design methods and approaches may increase. Students may become more independent when working on a design, also when they get stuck. Their stress level may decrease and their pleasure to design may increase.

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Critical Thinking in Problem Exploration in Design and Technology Design Project

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Abstract
The current study aimed to identify and clarify students' critical thinking processes in problem exploration. The current study will adopt the definitions of critical thinking conceptualized by Paul and Elder and, at the same time, attempt to apply the concept of elements of reasoning and intellectual standards to achieve the objectives of this study. By using questions to deconstruct the elements of reasoning when exploring problems, the intellectual standards for reasoning in problem exploration can be articulated. Using a qualitative approach to conduct a collective case study, 15 design journals completed by students in the upper secondary Express course in Singa Secondary School are used as objects of study. The primary source of data is collected via the documentations in the design journals. Using intellectual standards for reasoning in problem exploration to interpret the documentations in the design journals, students' quality of reasoning can be observed and consolidated. Based on the findings, the following conclusion can be presented. Firstly, to achieve depth, accuracy and unbiased understanding of the problem, students need to research on information and data from different sources to triangulate the problem. Secondly, it is necessary for students to acquire necessary background knowledge in order to conceptualize problems accurate and clearly. Thirdly, the development of intellectual standards for reasoning relevant to the design process in D&T may be a potentially useful strategy for teachers to explicitly develop critical thinking skills in D&T.

Key words
critical thinking; reasoning; design education; design and technology; problem exploration; problem conceptualization

Introduction
In responding to the effects of globalization and the knowledge-based economy, a major curriculum review was undertaken in 1997 by the Ministry of Education, Singapore (MOE) to rethink its goal and direction for the future (Poon, Lam, Chan, Chng, Kwek & Tan, 2017). A knowledge-based economy shifted the efficiency driven education into an ability driven education, where ability for life-long learning by its people is key to the sustainability and economic growth of Singapore (Goh & Gopinathan, 2008). The major curriculum review in 1997 led to the inception *Thinking School Learning Nation* (TSLN) in the same year (Poon et al., 2017). TSLN was considered as the pivotal policy shift toward 21 Century Competencies (21CC) education and the defining moment that aimed to systematically educate 21CC by concentrating resources on teachers, infrastructure and technology with the aim to prepare Singapore's students with the necessary knowledge and skills for the future (Poon et al., 2017).

The importance of critical thinking as part of the 21CC required of a student can be articulated with the policies and initiatives that came after the TSLN. To enhance the pedagogical change that set out in TSLN, the *Teach Less, Learn More* (TLLM) initiative was introduced in 2004 and subsequently launch in 2005. The TLLM set out to enhance the quality of education through reduction in syllabus content to encourage active learning and independent learning; and also, to enhance critical thinking and inquiry-based learning among students (Tan, Koh, Chan, Pamela & Hung, 2017; Koh, 2013). The revision in the *Desired Outcomes of Education* in 2009 further emphasized the importance of critically thinking in the four desired outcomes of the student (Tan et al., 2017).

Supporting the revised *Desired Outcomes of Education* in 2009 was the formalization of the *Framework for 21CC and Student Outcomes* in 2010 that represented one of the most significant developments in Singapore's efforts for 21CC education (Tan, 2013; Poon et al., 2017). As part of the three broad areas of emerging 21CC, where they are recognised as vital to helping Singapore's young people strive in the 21st century, critical thinking and inventive thinking are included. Since its formalization in 2010, 21CC framework has been infused into the academic curriculum, co-curricular activities, character and citizenship education, as well as Applied Learning Programmes for secondary schools (Tan et al., 2017). However, at the moment, few studies had been done to understand how critical thinking and creativity is being developed systematically through the implementation of pedagogy and practices in D&T at school level (Chia & Tan, 2007; Lim, Lim-Ratnam & Atencio, 2013; Loh, Kwek & Lee, 2015, 2017; Tan, 1996).

As part of a broader study to understand students' critical thinking process in D&T projects, the main focus in this current study is to identify and clarify students' critical thinking processes in the problem exploration. The findings will contribute to the understanding of how critical thinking may be systematically developed through D&T and also contribute to the international pool of knowledge on the practices in D&T education.

Critical Thinking

To be able to identify critical thinking processes, the literature review will first clarify the definitions of critical thinking and the kind of characteristics critical thinkers are expected to show. After that, how critical thinking may be assessed will be reviewed.

What is Critical Thinking?

Conceptualizing critical thinking may be divided by the generalist (domain-general) or the subject-specific (domain-specific) approach (Butler, 2017; Moore, 2004; Davis, 2006). The generalist approach conceptualises critical thinking as a set of skills that may be applied across subjects and disciplines (Moore, 2004), whereas, the subject-specific approach believes that critical thinking is closely tied to the subject or domain which it is applied. This is because, the set of critical thinking skills varies among the different domains or situations in which it is applied to (Moore, 2004).

While the definitions of critical thinking remain varied, they tend to have similarities with considerable overlaps (Halpern, 2014; Butler, 2017). Based on a study of literature review on critical thinking by Fischer & Spiker (2000), most definitions of critical thinking include reasoning/logic, judgement, metacognition, reflection, questioning and mental process. Butler (2017) mentioned that most definitions of critical thinking involved the attempt to achieve a desired outcome by thinking rationally in a goal-oriented fashion. Other studies also seemed to have obtained a consensus among policy makers, employers and educators who agreed that critical thinking involves constructing a situation and supporting the reasonings that form a conclusion (Jones, Dougherty, Fantaske, & Hoffman, 1995; Jones et al.,1995). In a way, this "common consensus" on critical thinking definitions tend to tie critical thinking with reasoning.

One of the mainstream concepts of critical thinking was developed by Ennis (1991, 1993, 2018), where "critical thinking means reasonable reflective thinking that is focused on deciding what to believe or do" (Ennis, 1991, p.8). Taking the generalist approach in defining critical thinking, Ennis (1991) considered critical thinking as an important part of problem solving. To provide more clarity on the nature of critical thinking, Ennis (1991) explained the conceptualization of the critical thinking definition through the decision-making process. Decisions about belief or action that generally occur in problem solving should have some basis. This basis may consist of observations, information and/or some previously accepted propositions. A decision is made through the inferences of this basis. Thus, when making and checking decisions independently, an ideal critical thinker should exercise a group of critical thinking dispositions where any decision made should be justifiable and able to be articulated to others (Ennis, 1991, 2015). According to Ennis (2018), other well-known definitions such as the one by Scriven and Paul (1987), as well as definitions by Seigel (1988), Facione (1990), Fisher and Scriven (1997) and Kuhn (2015) are not significantly different from his or from each other.

Scriven and Paul (1987) described critical thinking as a disciplined process that actively and skillfully conceptualize, apply, analyze, synthesize, and/or evaluate information gathered from/or generated by observation, experience, reflection, reasoning or communication, to guide one's belief and action. In other words, critical thinking is a self-directed, self-disciplined, self-monitored and self-correcting thinking process that involves analyzing and evaluating thought processes with the intention of improving them (Paul & Elder, 2002, 2019). The conceptualization of the definition of critical thinking by Scriven and Paul (1987) and Paul and Elder (2002, 2019), rest on the basis that thinking can be analyzed and evaluated by first taking thinking apart and then applying standards to those parts. Paul and Elder (2002) explained that whenever thinking occurs, reasoning occurs. This is based on the concept that thinking always occurs for a purpose within a point of view based on assumptions that lead to implications and consequences (Paul & Elder, 2002, 2019). Concepts, idea and theories are used to interpret data, facts and experiences in order to answer questions, solve problems and resolve issues (Paul & Elder, 2002, 2019). As such, all thinking processes involve generating purposes, raising questions, using information, utilizing concepts, making inferences, making assumptions, generating implications and embodying a point of view (Paul & Elder, 2002, 2019). These eight areas form the eight basic structures of thinking, which Paul and Elder (2002, 2019) also called the elements of reasoning that are present in reasoning across subjects and cultures. By deconstructing thinking into the elements of reasoning, each element of reasoning may then be assessed.

A search for other alternatives to defining critical thinking was conducted but they are merely similar alternatives to those that have been mentioned earlier. One such alternative is offered by Halpern (2014) where critical thinking is used to describe thinking that is purposeful, reasoned and goal directed and is involved in solving problems, making inferences, calculating likelihood and decision-making. Thus, it is the use of rationale thinking to achieve a desired outcome. Others described critical thinking as a process to determine whether claims and arguments used in the process of reasoning are sound by making informed and evaluative judgements (Butterworth & Thwaites, 2013; Hughes, Lavery & Doran, 2010).

How do we know when a person exercised critical thinking?

The earlier section provided a review on the common overlaps in defining critical thinking. To further clarify critical thinking, what type of skills and abilities will a person display when critical thinking is exercised? Ennis (1991, 2018) conceptualized a set of general critical thinking dispositions and abilities of an ideal critical thinker. Expanded from the list published in 1991, the latest list included 12 dispositions and 18 abilities (Ennis, 1991, 2018). Mainly using examples from his experience as a juror, Ennis (1991) exemplified and elaborated on each of the dispositions and abilities to explain his conception of an ideal critical thinker. Similarly, Halpern (2014) provided a list of 15 generic skills that a critical thinker will possess. In addition to acquiring skills, it is necessary to develop the attitude or disposition of a critical thinker. Thus, Halpern (2014) included 8 attitudes or dispositions that a critical thinker should exhibit, and just to name a few, willingness to plan, flexibility, and persistence. Among the skills and dispositions suggested by Ennis (2018) and Halpern (2014), some of the overlapping skills and dispositions are the use of existing knowledge, metacognition, understanding and using math, graphs and diagrams for communication, judging creditability of information, making justifiable decisions, open-mindedness, taking a position when there is sufficient evidence and an ability to employ critical thinking skills and dispositions.

To facilitate reasoning, Hughes, Lavery and Doran (2010) suggested that three types of skills are necessary for critical thinking; they are interpretive skills, verification skills and reasoning skills. Language which is used to express thoughts are essential in the process of thinking which is part of reasoning. As such, interpretive skills are necessary to clarify and interpret the meaning in statements and arguments as clearly as possible to remove ambiguities. In order to determine statements that had been clarified in terms of truth and falsity, verification skills are needed. Finally, reasoning skills are needed to assess the arguments in terms of whether the premises are relevant and supportive to the conclusion.

In order to exercise critical thinking, possessing the skills may not necessarily mean that critical thinking has been achieved. For example, the ability to analyze evidence and make justified decisions does not mean that a good decision is made based on the quality analysis of the information at hand. In determining if a person has exercised critical thinking, Bailin (1999) emphasized that it is the quality of thinking, not the process of thinking, that differentiate critical thinking from ‘uncritical thinking’. As such, not all thinking activities that aimed at decision making can be considered as critical thinking and the quality of thinking has to fulfill a certain level of acceptable standard (Bailin, 1999). In assessing critical thinking skills, many such assessments come in the form of a critical thinking test.

According to Ennis (1993), no subject-specific tests were found but a list of general-oriented-based tests could be consolidated during a study on critical thinking assessment. Almost all the tests were multiple choice test which were good for efficiency and cost, but not comprehensive enough in effective testing for many significant aspects of critical thinking such as being open-mindedness and drawing warranted conclusions cautiously (Ennis, 1993). Ennis (1993) further suggested that open-ended critical thinking tests were necessary for comprehensive assessment, unless appropriate multiple-choice tests were developed. In a recent study, Butler (2017) provided a brief review on the reliability and validity of critical thinking assessments that measure critical thinking skills and those that measures critical thinking dispositions. These tests are used mainly to assess student learning outcomes so as to provide formative feedback to improve instructional methods. In fact, much of these tests may also be seen as an advocate for teaching of critical thinking explicitly rather that implicitly.

While critical thinking skills and dispositions can be assessed using test-based assessment, Paul and Elder (2002, 2019) provided an alternative model for assessing the quality of critical thinking. Paul and Elder (2002, 2019) suggested that a well-cultivated critical thinker should exhibit the following characteristics:

- Raises vital questions and problems, formulating them clearly and precisely
- Gathers and assesses relevant information and effectively interprets it
- Comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards,
- Thinks open mindedly within alternative systems of thought, recognizing and assessing as need be, their assumptions, implications, and practical consequences
- Communicates effectively with others in figuring out solutions to complex problems

The formation of these characteristics is based on a conceptual framework where the basic structures of thinking, also called elements of reasoning, can be assessed using a set of standards (also called intellectual standards). Intellectual standards can be conceptualized as standards necessary for making sound judgements and rational understanding (Elder & Paul, 2013b; Paul & Elder, 2008). The intellectual standards are formed based on the argument that all modern natural languages (such as English, German, French, Arabic, Japanese) provide their users with a wide variety of words that, when used appropriately, serve as plausible guides in the assessment of reasoning (Elder & Paul, 2013a; Paul & Elder, 2008, 2014). Words such as clarity, accuracy, relevant, significant, logical and so forth are identified as intellectual standard words (Paul & Elder, 2008, 2013, 2014). Though the focus on determining intellectual standard words are based on the availability in English language, it is hypothesized that similar web of intellectual standard words exist in every natural language, though perhaps with differing nuances (Elder & Paul, 2013a; Paul & Elder, 2008, 2014). Paul and Elder (2002, 2019) suggested that there are at least 9 intellectual standards (also called intellectual standard words), recently expanded to 10. The intellectual standards are *clarity*, *accuracy*, *precision*, *relevance*, *depth*, *breadth*, *logicalness*, *significance* and *sufficiency* (Paul & Elder, 2002, 2019). Using questions to deconstruct reasoning, a framework of how intellectual standards can be applied to these questions to assess quality of critical thinking has been further explained by Paul & Elder (2002, 2008, 2019).

Adopting a working definition and a mode of assessing quality critical thinking

The different ways of defining critical thinking seems to be just different ways of cutting the same pie. The main concept of critical thinking process revolved around the process of reasoning. With this assumption, Paul and Elder provided a clear structure to unpack reasoning into parts. Without the need for a standardized critical thinking assessment test, Paul and Elder had also created a model to allow the quality of reasoning to be assessed using the intellectual standards, through questioning techniques. Furthermore, this model is flexible in application across different subject areas and provides a great potential for the application in this study. With above considerations, the current study adopts the definitions of critical thinking conceptualized by Paul and Elder (2002, 2008, 2019) and at the same time, attempts to apply the concept of elements of reasoning and intellectual standards to achieve the objectives of this study.

Research Question

This study sought to answer the following main question.

- Given an ambiguous theme, how do students exercise critical thinking to conceptualize the problems that are related to the theme?

Research Methodology

Research Approach and Method

The current study employed a qualitative research methodology to gain insights on students' application of critical thinking to unpack an ambiguous theme to conceptualize problems that are related to the theme. The method used for the current study was the collective case study as described by Goddard (2010). Collective case study involves more than one case that may or may not locate in one site. The main purpose of collective case study is to explore cross-case comparisons and draw generalizations from the entire population to understand the phenomenon deeply from a variety of perspectives. As the number of cases studied should share some common links or similarities, a common set of research questions should be developed to guide the study of each individual case.
The current study will be conducted within a single site, which is a government secondary school in Singapore. The considerations for choosing the site are shown in Table 1.

Table 1. Criteria for choosing a study site

Reasons to select Singa Secondary School as Study Site
1. As a pilot school for implementing Framework for 21CC in 2010, the school will have more experience with the review and implementation of pedagogy and practices to develop critical thinking.
2. Widely recognised by the D&T fraternity in Singapore, for the last 15-17 years, for innovation in pedagogy and teaching practices, and the ability to achieve excellent student outcomes. D&T teachers from different parts of Singapore often seek opportunities to visit the school to learn from the teachers.

Singa Secondary School (the school name used is a pseudonym), was identified as a potential site for the study. The study was subsequently conducted with permission from school leaders, head of department and D&T teachers. The selection of Singa Secondary School was based on the following reasons in Table 2.

Table 2. Reasons for choosing the current study site

Criteria for Selection of Study Site
1. School should be recognised to implement a progressive D&T programme
2. D&T teachers are active in professional sharing in the Singapore D&T fraternity.
3. Profile of students studying D&T consists of a mix of academic abilities

Objects of Study

The objects, or cases, for this study are the design journals done by upper secondary students in Design Project A for a D&T Express course. Design Project A is a major design project that all upper secondary school students in the Express course (between the age of 15 and 16) have to go through in Singa Secondary School. The main purpose of Design Project A is to allow students to exercise their knowledge and skills learned in D&T up till the point of Design Project A to engage in a full design process that starts with a given theme and ends with a proposed working prototype. In this project, students take main control of the design process as teachers supervise. The given theme for Design Project A differs yearly, but the tasks required, and assessment criteria are consistent.

Design journals done by students in Design Project A are regarded by D&T teachers in the school as a detailed record of students' thinking and decision-making processes in the process of design. As much as possible, students are required to record any form of explorations, research, ideation, experimentation and evaluation processes related to problem identification, ideation, idea development and prototyping. Thus, the used of design journals as objects of study is based on the assumptions that design journals are a detailed collection of students' insights during the design process. In the selection of design journals for study, the following considerations were made. (refer to Table 3)

Table 3. Considerations for selecting study cases

Considerations for Selecting Design Journals as Cases
1. The design journals should be done by students who were conscientious in completing their work. This is to ensure that any deficiency in their performance in the design journals are due to their abilities rather than the lack of effort.
2. The design journals should be done by students who had gone through similar D&T curriculum before attempting Design Project A. This is to reduce the disparity of student performance due to the difference in terms of content knowledge and skills.
3. The design journals should be representative samples that reflect the quality of work done by majority of the D&T students in Design Project A. The design journals selected for study should not be the outliers in terms of performance.

A review of the D&T curriculum of Singa Secondary School was first done. Being selected as a pilot school for 21CC in 2010, the D&T department had reviewed the curriculum for the lower and upper secondary D&T Express course. Started in 2012, critical thinking is taught more explicitly in lower secondary D&T. The strategy for explicit teaching of critical thinking in problem exploration was explained by Loh, Kwek & Lee (2015, 2017). Thus, upper secondary students engaging in the Design Project A from 2014 onward would have gone through a similar D&T programme starting from lower to upper secondary. Using available archives, 15 design journals completed between 2014 and 2016, and supervised by two teachers were selected as study samples. (Refer to Table 4)

Table 4. Number of journal archives used for study between 2014 and 2016

Year:	No. of Archived Journals Used	Supervised by:
2014	8	Teacher A
2015	1	Teacher A
2016	6	Teacher B

According to information related to class deployment, the academic profile of students supervised by the two teachers were similar. Throughout the year, it is a practice in the school that all D&T teachers will often share and discuss teaching and learning, and students' progress for all levels (secondary 1 to 4) of D&T learning. These forms of meeting provide professional development for all D&T teachers and also reach consensus on what to expect for student outcomes for each level. Though the selected design journals for this study were supervised by two D&T teachers, the disparity in the quality of supervision, teaching and student academic abilities related to this study were considered to be minimum.

Research Design

The primary set of data was collected via students' documentations in the design journals. The scope of collection covers students' documentation during the problem exploration process. The start of the problem exploration process began with students receiving an ambiguous theme in the form of a "word" such as, Movement, Storage, etc. Then after this, students would start the exploration by defining the theme and associating the theme to related areas or objects to explore and conceptualise problems. Students' documentation will include written and printed text, sketches and photos.

By consulting the D&T teachers, teachers' expectations of students during problem exploration were first collected by the author (refer to Table 5). These expectations were in line with the assessment rubrics for Design Project A. Though the critical thinking model by Paul and Elder (2008) can be applied to all reasonings across different fields, the importance of some intellectual standards may be different in different fields. Thus, it is necessary to contextualize the intellectual standards within the field and to articulate the intellectual standards that are most important for reasoning (Paul & Elder, 2008).

Table 5 provided the context for the author to contextualize the intellectual standards relevant to the current study. Based on Table 5, questions were used to deconstruct reasoning when exploring problems and then after, intellectual standards were applied to answer these questions (Paul & Elder, 2008). By answering the questions, the intellectual standards essential to good reasoning in problem exploration can be articulated (refer to Table 6). Using Table 6, the author was able to observe students' critical thinking processes by interpreting the documentations in the design journals. To increase validity of the interpretations, any queries related to the documentations were clarified with teachers before further interpretations. In addition, all observations were provided to the D&T teachers for clarification so that any misinterpretation could be corrected.

As the author is the main interpreter of the data, it is important to reflect on any possible biases that may influence the outcome of the interpretations. The author is an experienced D&T teacher who had also led a D&T department in the past. It is important that during the interpretation of data that the author kept an open mind on the process of problem exploration embarked by the students, instead of looking for a prescribed process that the author may be very familiar with.

Research Implementation

During the implementation of the study, the documentations in each design journal were first studied to understand the problem exploration process embarked by the student in totality. Then after, using Table 6 to interpret the documentations, observations of each student's good reasonings and weak reasonings with respect to each of the elements of reasoning during problem exploration were recorded. After all the 15 design journals, or cases, were interpreted and observations recorded, common and different patterns in students' reasoning for each element of reasoning could be identified and clarified.

Table 5. Teachers' expectations in problem exploration process

Teachers' expectations of student in problem exploration process
Student to check the dictionary(s) to understand the meaning of the words.
Student uses a mind-map to explore the theme. They can indicate possible problems that they can think of, observe, research from the internet on the mind-map.
Student can go around their neighborhood or different places to observe people, places or products and take photos of the possible problems, inconvenience, etc.
Student can check on the internet on websites like the forum, social media or news to find possible problems.
Student can look at the products or picture of products to analyse for possible problems, area for improvements, opportunity to design.
Student can talk to people to find out problems that they faced.
Student is expected to write his/her problems clearly with detail descriptions and the causes and effects of the problem logically.

Table 6. Deconstructing reasoning and articulating Intellectual Standards for good reasoning

Elements of Reasoning during Problem Exploration	Questions to deconstruct reasoning	Intellectual Standards for good reasoning in Problem Exploration
Purpose	□ Is student clear about the purpose of problem exploration?	□ Display ***clarity*** and ***consistency*** in purpose by exploring and identifying design problems that are related to the theme.
Questions	□ Is student able use relevant questions to understand the given theme? □ Is student able to use relevant questions to understand the problems? □ Is students able to use sub-questions to help them to understand the theme or to understand the problems?	□ ***Relevant*** questions are used to unpack the theme. □ ***Relevant*** questions are used to clarify the problems. □ Sub-questions are used break down the theme or problems to achieve ***clarity*** in understanding.
Point of View	□ From what point of view did student look at the problems?	□ Problems identified are seek other point of view to achieve ***fairness*** and ***clarity***.
Assumptions	□ Are student's assumptions justifiable and reasonable based on evidence or past experience? □ Is student clear about the assumptions that he/she is making?	□ Problem identified are based on student's assumptions which are ***justified*** and ***clear***.
Information	□ To what extend is student's reasoning supported by relevant, accurate and adequate information? □ Did student managed to state the evidence used to define a problem clearly? □ How clear, accurate, and relevant are the information to support student's argument?	□ Source of information in understanding the theme is ***reliable*** and ***accurate***. □ Problems identified are supported by ***reliable*** and ***accurate*** evidence.
Concepts and Ideas	□ Are the key ideas and concepts that guide students' reasoning to be clear, accurate, relevant or deep?	□ The concepts and keys ideas that guide students in identifying the problems are ***clear***, ***accurate***, ***relevant*** or thought ***deeply***.
Implications and Consequences	□ What implications and consequences follow student's reasoning about the problems? □ Are students able to clearly and precisely articulate the possible implications and consequences of the problems?	□ Inferences on the design problems based on the evidence showed possible implications and consequences ***clearly***.
Inference	□ Is student able to make inferences that are justified, reasonable, clear and logical?	□ Inferences on the design problems are ***based on evidence*** that shows the possible cause to the problems. The causes are explained ***logically***, ***reasonable*** and ***clearly***.

Findings

Observations of Good Reasoning in Problem Exploration

Based on the study of the 15 design journals, the critical thinking processes exercised by the students to conceptualize problems from an ambiguous theme could be broken down into the different elements of reasoning. By applying the intellectual standards for good reasoning in Table 6, the quality of students' critical thinking could be assessed through the documentation in the design journals. In this section, Table 7 consolidates the observations of common and different patterns of good reasoning exercised by students. Each observation is accompanied by an example presented via a figure indicated in the last column of Table 7. As much as possible, examples taken from different design journals are presented.

Table 7. Observations of Good Reasoning in Problem Exploration

Elements of Reasoning during Problem Exploration	Observations of Good Reasoning in Problem Exploration (the number in the bracket represents number of design journals with similar observation)	Refer to the following figures
Purpose	All students started with mind maps to help them to brainstorm areas that are related to the theme and follow by branching out to suggest related problems and/or necessary improvements. The mind maps were articulated clearly to show the relevance and consistency with the theme. (15)	Figure 2
	Some students also used synonyms to guide them in thinking about problems related to the theme further shows consistency when probing the theme. (3)	Figure 4
	During the elaboration of the problem, student used questions such as “link to the theme?” to guide him/her to frame problem related to the theme. This shows student’s consistency in keeping focus on the theme. (1)	Figure 5
	Students look for relevant picture of products related to the theme to analyse and look for possible problems/improvement or opportunity for solution that are linked to the theme. (6)	Figure 6
Questions	Some students used sub-questions to help them in elaborating the problems clearly and logically. (3)	Figure 5
	Some students also used 5W1H as questioning technique to guide them in thinking about relevant problems related to the theme. (2)	Figure 3
Assumptions	Assumptions about the problem are generally clear because they are able to explain the cause and effect related to the problems. (15)	Figure 6
Information	Students referred to reliable online dictionary so as to understand the meaning of the theme. (9)	Figure 1
	Students referred to more than one online dictionary to increase accuracy in their understanding of the meaning of the theme. (6)	Figure 1
	Problems identified were supported by photos of the problem situations taken by students or from the internet to justify the authenticity of the problem. (9)	Figure 5
Concepts	In generally, students are able to apply key concepts and ideas such sustainability, hygiene, space constraint, user convenience, safety, health, and etc. to guide them identify problems. (15)	Figure 8
Implications and Consequences	Students made inference based on photos related to the problem to present clearly the possible implication clearly and logically. (9)	Figure 5
	Students explained the cause and effects of the problems logical. (15)	Figure 5
Inferences	To define the theme, students made inferences that follow from definitions and meaning, of the theme, stated in the dictionary to form their own understanding of the given theme that is reasonable and justifiable. (9)	Figure 1
	Students made logical inference based on photos related to the problems to explain or present the possible causes. The causes were explained clearly. Some students supplemented with drawings to illustrate the problem clearly. (9)	Figure 7

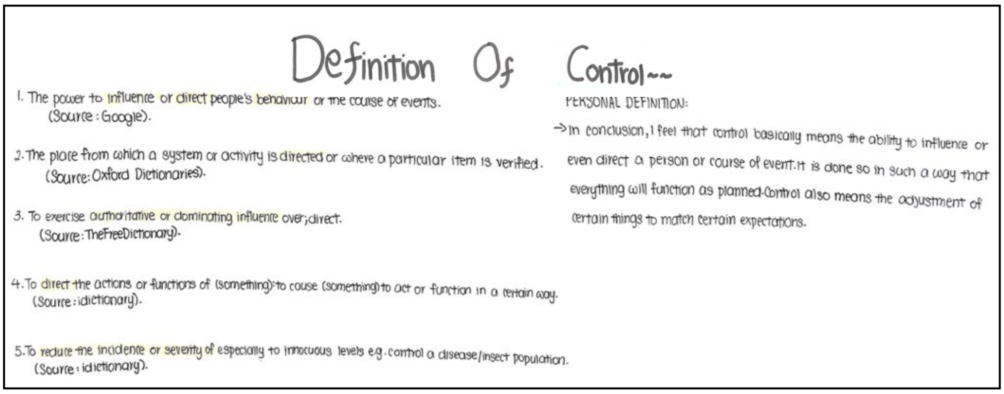


Figure 1. Student B defined the theme based on different sources

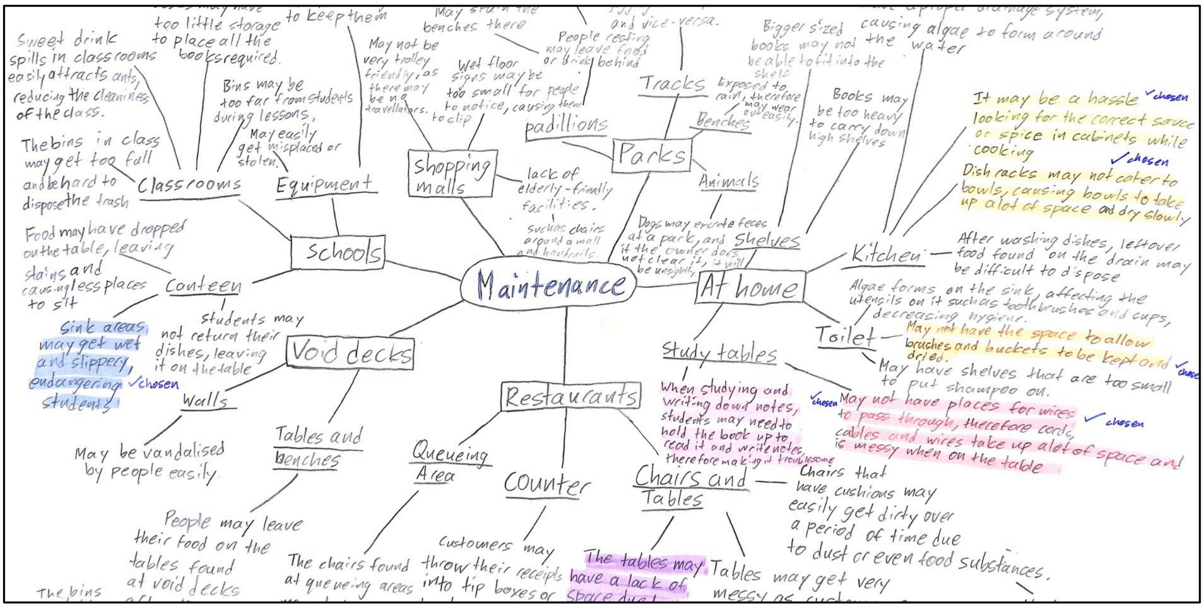


Figure 2. Student I brainstormed areas related to the theme

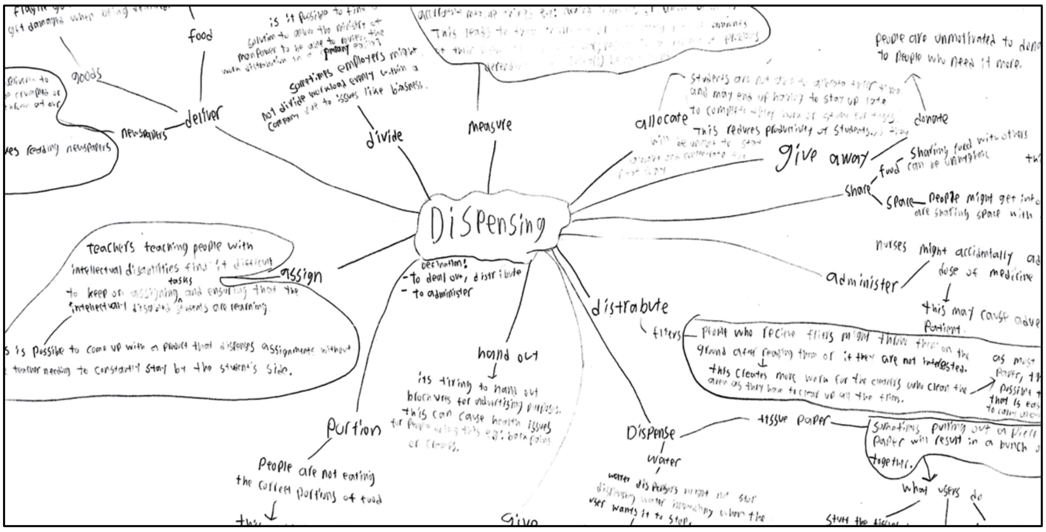


Figure 3. Student J used 5W1H during to define the theme

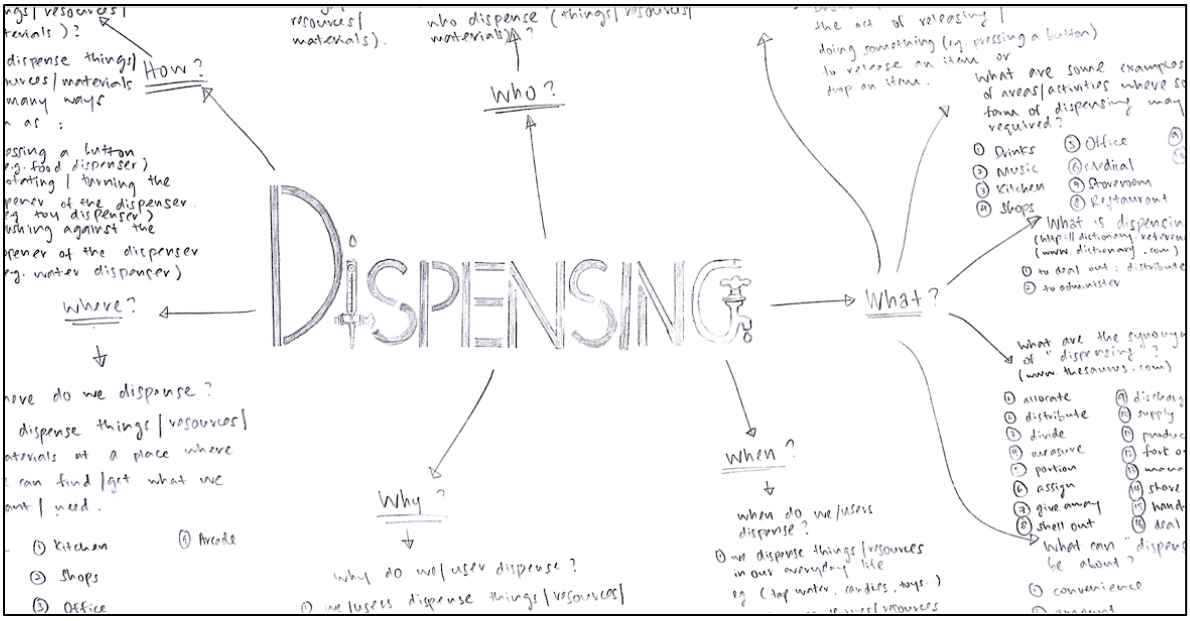


Figure 4. Student K used synonyms to brainstorm areas related to theme

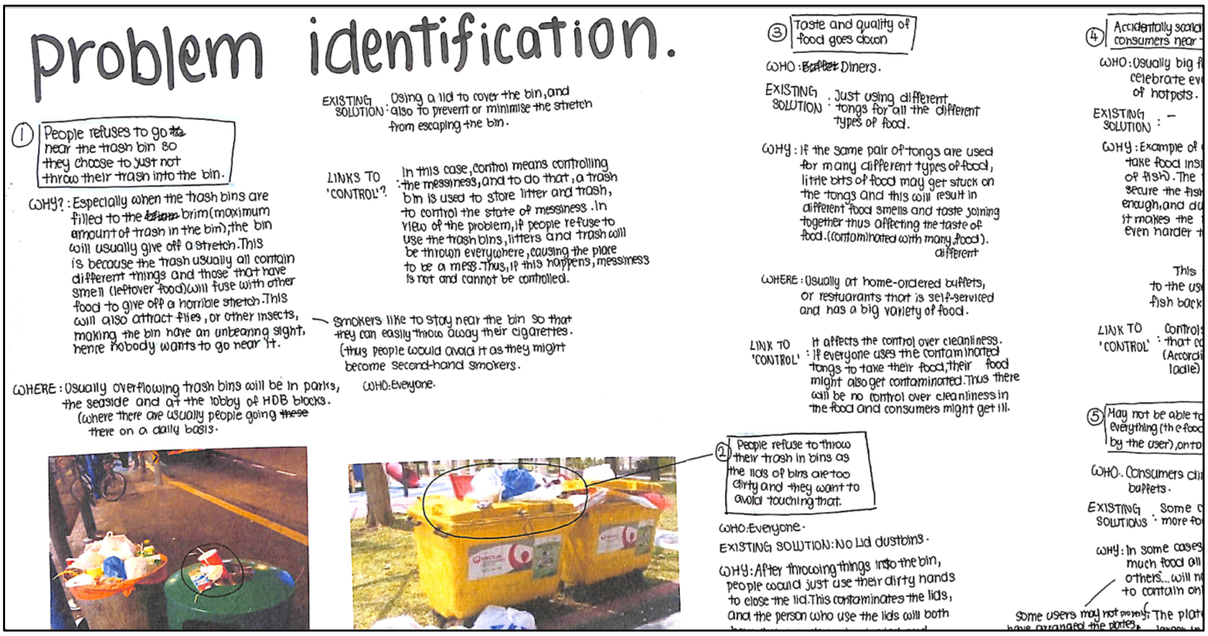


Figure 5. Exploration of possible problems by Student B

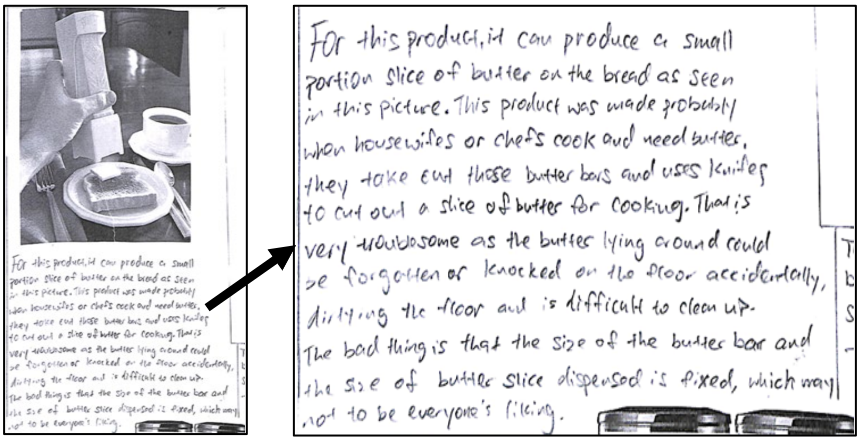


Figure 6. Student O analyzed products to look for potential problems

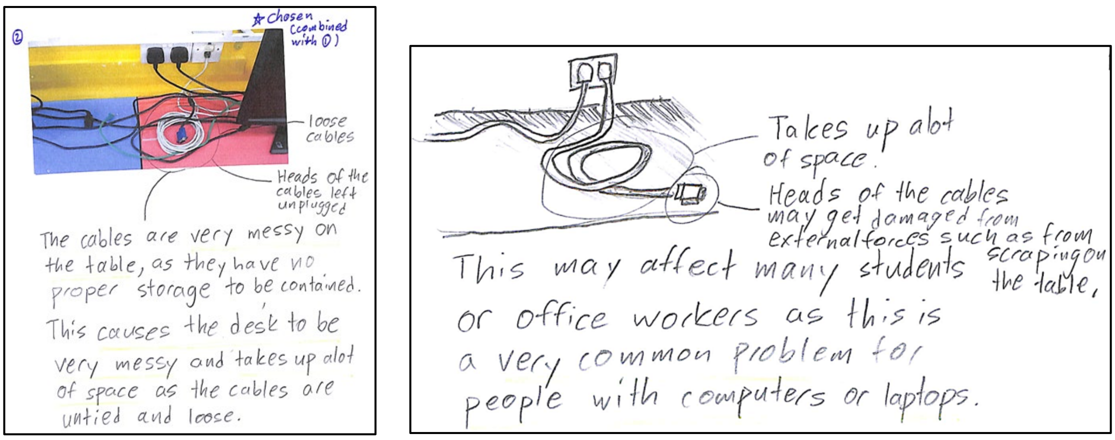
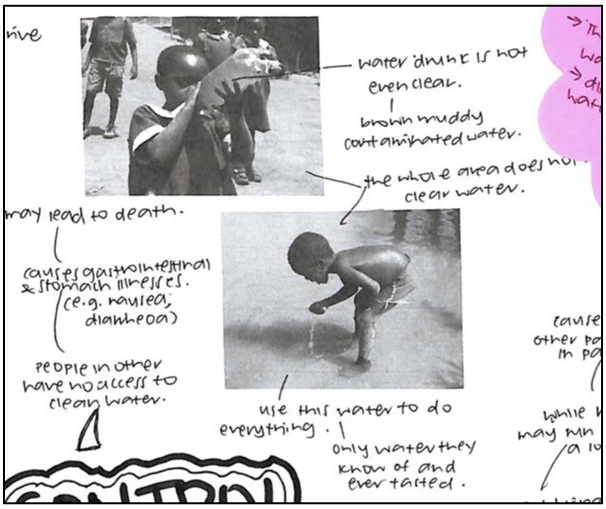
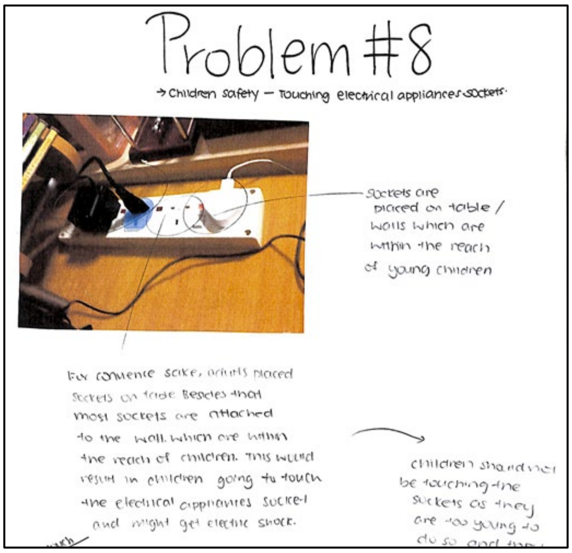


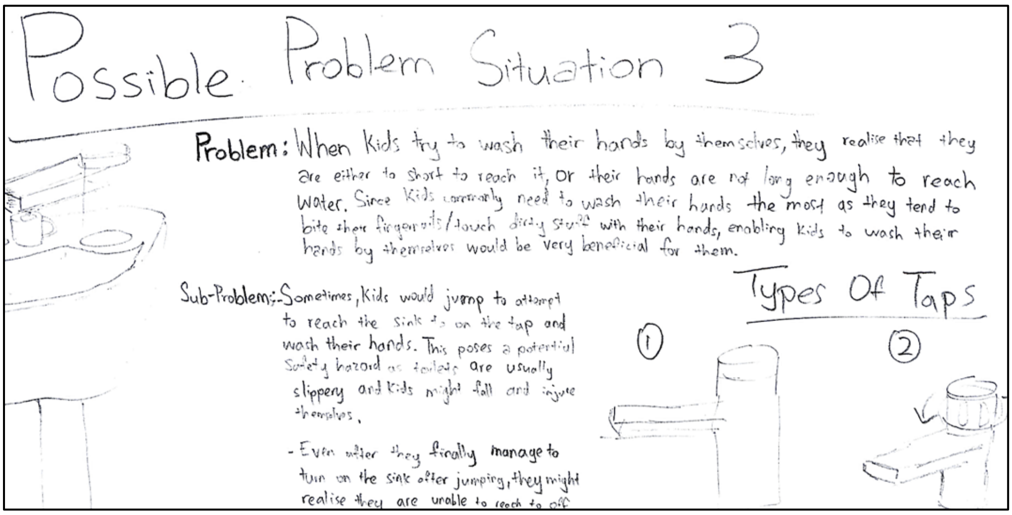
Figure 7. Student I explained a potential problem using photo and sketch



(a)



(b)



(c)

Figure 8. Students applying concepts and ideas such as, (a) environment sustainability and health, (b) electrical safety and (c) user convenience

Observations of Weak Reasoning in Problem Exploration

Among the good reasoning observed, there were also instances where examples of weak reasoning surfaced. The observations for weak reasoning are presented in Table 8. Examples of weak reasoning observed did not form the majority of the cases, there were just a couple weak reasonings among some of the good reasonings within a single design journal or a single case. Thus, the number of design journals associated to such weak reasoning are not indicated. Instead, the examples of weak reasoning will be further elaborated in this section to provide a deeper insight into some of the reasoning issues. More importantly, the observations of weak reasoning will serve as important insights to inform teachers that even though students may be able to exercise good reasoning skills in general, there may be instances where their reasoning are off the standard. As such, teachers should be aware of instances where students may not be exercising good reasoning and provide interventions to redirect students to achieve quality critical thinking.

Table 8. Observations of Weak Reasoning in Problem Exploration

Elements of Reasoning during Problem Exploration	Observations of Weak Reasoning in Problem Exploration
Assumptions	Although problems identified were elaborated with cause and effects that seem logical from students' perspectives. However, some may students lack certain background knowledge to comprehend the problems or lack of consideration of certain factors of the problems. Thus, the evidence presented were not sufficient to justify the conclusions made towards the problem. Some of the assumptions made on some of the problems were not supported by any evidence.
Information	Some problems identified did not any evidence to justify. Most problems were only supported by evidences from the photos taken. No other evidences were used to justify the problem.
Implications and Consequences	A couple of problems were elaborated clearly with cause and effect, but the depth of understand problems stated were superficial or the probability of the problem to occur may be uncommon.
Inferences	Problems inferred from the photos related to the problems did not follow the evidence resulting in drawing irrelevant conclusion.

Although in most cases, students provided evidence to support their inferences or assumptions of the problem, sometimes they might also be making inferences or assumptions without any evidence to support them. In this case, it might be associated to students' weak reasoning or students might have consulted relevant stakeholders to hear their point of view in order to understand the problems before documentation. As there was no documentation that indicated reasoning through a point of view or any other forms, interpretations could not be made accurately. In most cases, students' main source of information came from photos taken either by themselves or from the internet. As such, other forms of evidence, data, information should also be brought to the surface in order to achieve accurate claims or assumptions about the problems. This could be explained by how Student O explored possible issues with the butter dispenser in Figure 6. Student O made some logical assumptions on issues related to the disadvantages of dispensing a fixed quantity of butter slices and possibility of accidentally knocking the dispenser onto the floor. But Student O assumed that this dispenser was designed for dispensing butter for cooking instead of using as a bread spread. Thus, a dispenser for cooking and for bread would probably be designed differently. If Student O had collected other sources of information about the dispenser, perhaps his/her inferences about the possible problems may have been more accurate.

In another case, Student M mentioned that the stacking of bowls and cups on the table in a buffet restaurant will be an issue when kids run into the table and hence cause the bowls and cups to fall (refer to Figure 9). Student M later reflected that the problem might not be realistic as the probability of that happening was low. In a way, Student M's understanding of the problem was not deep enough although clear implications and consequences were provided.

Lastly, there was a case where a student's inference did not follow the evidence provided. Student E mentioned the issue of "killer litter" in public flats (refer to Figure 10). "Killer littering" in Singapore refers to throwing litter out of the flats that may endanger lives. But the photo evidence provided by Student E was putting objects dangerously at the ledge rather than objects being thrown down the flats.

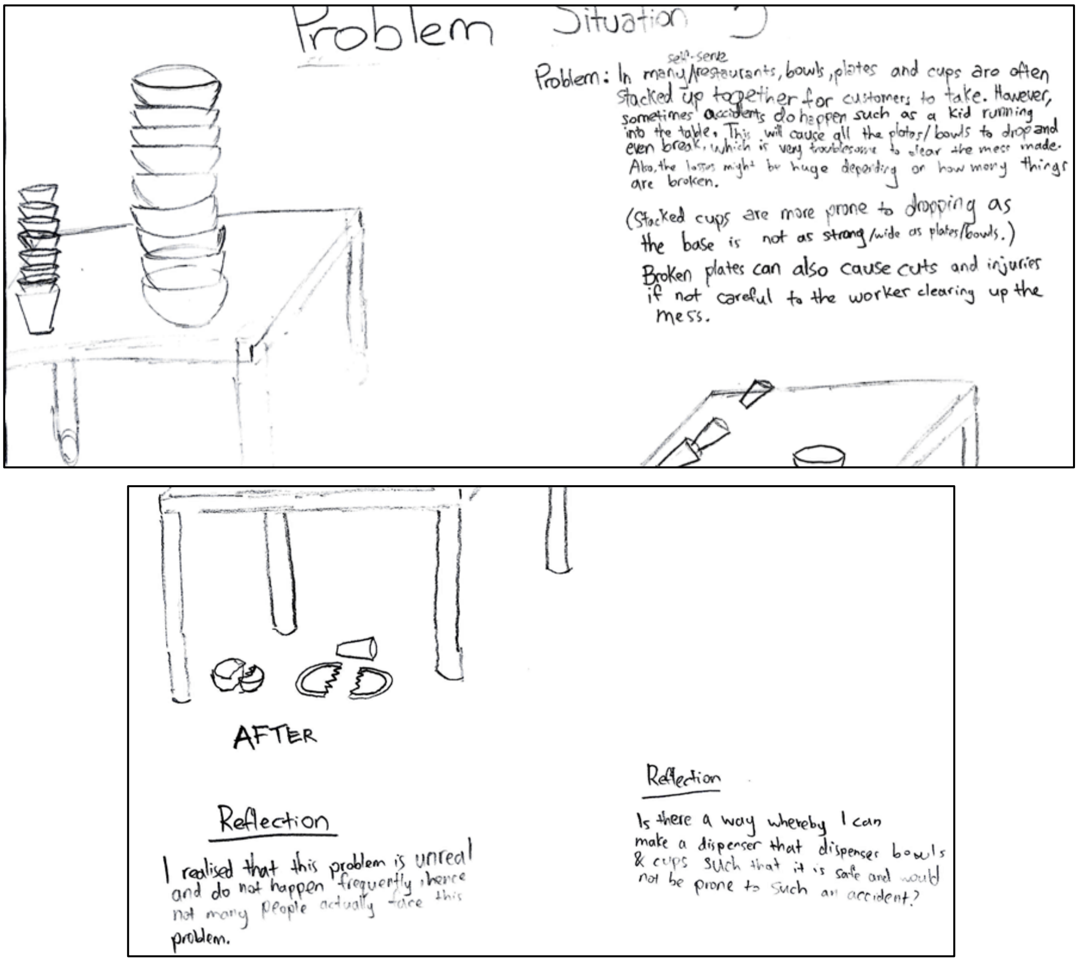


Figure 9. Inference of the possible problem that is superficial

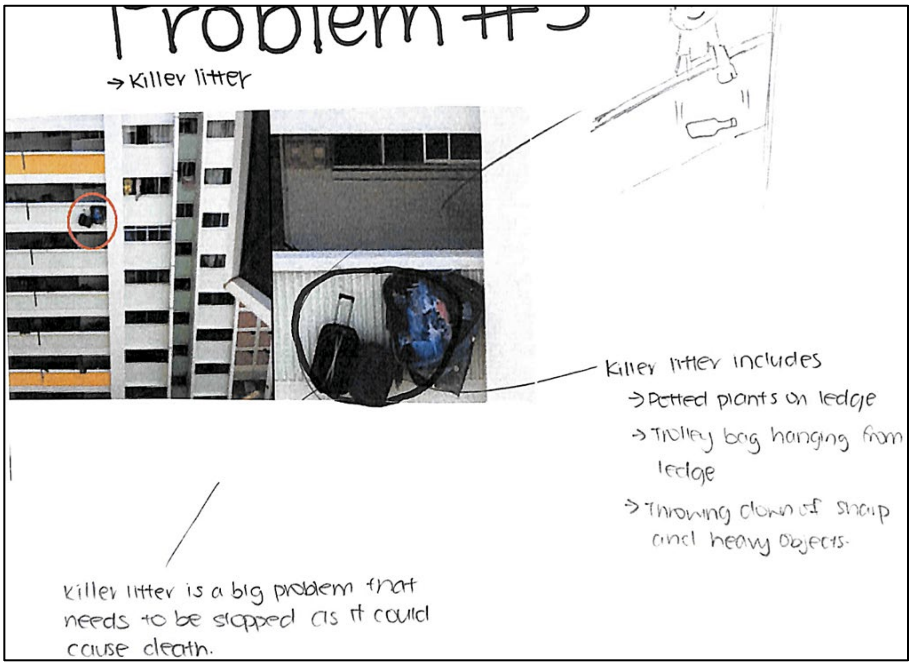


Figure 10. Inference made based on irrelevant evidence

Discussion

Using the critical thinking model by Paul and Elder (2002, 2008, 2019), this study showed a possibility of disserting the critical thinking processes embarked on by students in problem exploration. When given an ambiguous theme to identify and conceptualize possible problems, the findings have shown that students are capable of exercising good reasoning skills that are purposeful and focus on the given theme. Using a variety of approaches such as questioning techniques and information collection and analysis, students are able to clarify and justify their assumptions and inferences of the problems. More importantly students are able indicate the possible implications and consequences of the problems clearly.

But at the same time, the examples of weak reasoning surfaced during the study may have certain implications for D&T learning with respect to problem exploration. Firstly, although students may be able to provide justifications to conceptualize the problems, the accuracy and depth of understanding about the problem may not be sufficient as evidence is mainly from one source. This will impact on their solutions in the latter part of the design process if the understanding of the problem is superficial. Thus, using information and data from different sources to triangulate the problem is important to achieve depth, accuracy and unbiased understanding of the problem.

Secondly, some of the misconceptions about the problems are due to lacking prior knowledge related to the environment, stakeholders or related products. Thus, background knowledge is important for students to achieve an accurate conceptualization of the problem. This is supported by Bailin (1999) who considered that background knowledge is one of the key intellectual resource to achieve quality critical thinking. In a way, when supervising students in design projects, teachers may direct students to pick up necessary background knowledge during their research on the problems.

Thirdly, to enhance the quality of reasoning skills in students, it is necessary that students are constantly aware of their thinking and constantly assessing the strengths and weaknesses in their thinking. Thus, it will be necessary to work out and articulate the intellectual standards for reasoning, with respect to the elements of reasoning, for all parts of the design process. By increasing students' awareness of the intellectual standards for reasoning for all elements of reasoning and applying them during the design process, the quality of critical thinking of students may be improved. Although this approach may be a potentially useful strategy for teachers to explicitly develop critical thinking through D&T, further research is required to look into developing the intellectual standards for reasoning for all parts of the design process.

Limitations

As limitation to this study, current findings are mainly based on the documentation from the design journals. However, what goes into the discussions between student-teacher and student-stakeholder, that may influence students' understanding of the problems are not able to be clarified. This can be apparent as no observations could be found in the findings related to reasoning through other points of view. As the nature of seeking other points of view suggests, students might have sought other point of view during the conceptualization of the problems but did not document the information in the design journals. It was also clarified with the teachers during interpretation of documentations that students were not told to explicitly record what they have heard from others or the details related to any discussions with the teachers.

Conclusion

The current study aimed to identify and clarify students' critical thinking processes in problem exploration. This study adopted the definition that critical thinking revolves around reasoning. By using questions to deconstruct the elements of reasoning when exploring problems, the intellectual standards for reasoning in problem exploration could be articulated. Using a qualitative approach to conduct a collective case study, 15 design journals done by students in the upper secondary Express course in Singa Secondary School are used as objects of study. The primary source of data is collected via the documentation in the design journals. Using the intellectual standards for reasoning in problem exploration to interpret the documentation in the design journals, students' quality of reasoning could be observed and consolidated. Based on the findings, the following conclusions can be presented. Firstly, to achieve depth, accuracy and unbiased understanding of the problem, students need to research information and data from different sources to triangulate the problem. Secondly, it is necessary for students acquire necessary background knowledge in order to conceptualize problems accurately and clearly. Thirdly, the development of intellectual standards for reasoning relevant to the design process in D&T may be a potentially useful strategy for teachers to explicitly develop critical thinking skills in D&T.

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25.1

Digital Touch: Towards a Novel User-Experience Design Pedagogy

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Abstract
HCI and Industrial Design are both disciplines that are currently experiencing radical transformation in terms of their identity and scope. HCI has moved beyond its origins in human factors and cognitive psychology towards the proactive and generative design of experience. Industrial Design has similarly evolved from a concern with physical form and function-giving solutions to the holistic design considerations of the user's experience. Given the complexity and scale of this shifting design landscape, the response of design education must shift in methods and learning and teaching objectives. This paper provides the Design and Technology Education community with a research case study of innovation within HCI education, here situated within the broader context of Industrial Design education. We present a novel pedagogy for designing digital touch communications, developed through an interdisciplinary collaboration of HCI, Industrial Design, and Social Science academics, and advanced through a coursework assignment for 64 undergraduate Industrial Design and Technology students undertaking a User-Experience Design module at the School of Design and Creative Arts, Loughborough University (UK). We discuss the role of low-fidelity experience prototyping of digital touch interactions beyond screens, and the limitations of such an approach when engaged with by novice designers with entrenched material science understanding. We conclude the paper with a call for new educational '*tools*' to support and scaffold both the learning and teaching of design for digital touch experiences within a User-Experience Design context, and we offer our development of a Designing Digital Touch Toolkit as one such tool.

Keywords
digital touch; HCI; experience prototype; design pedagogy; user experience; multidisciplinary

Introduction

This paper explores what happens pedagogically when we move '*digital touch communication*' to the centre of a Human Centred Design (HCD) design process. Advances in haptics, virtual reality, and bio-sensor applications are re-shaping what can be touched as well as how it can be touched, shifting digital communication from '*ways of seeing*' to '*ways of feeling*' (Price et al., 2018; Jewitt, Leder Mackley, Atkinson & Price, 2019). While technological frontiers continue to be pushed, there is scope for innovation regarding the kinds of meaningful communication experiences and activities that these technologies might enable or support. We reflect on the ways in which current pedagogical experiences with design 'materials' and rapid prototyping shape design students' engagement with the design of digital touch experiences, and suggest an emphasis on the speculative, social, and sensory aspects of how touch experience might enhance their engagement.

The paper presents an ongoing interdisciplinary collaboration between the authors, academics in Human Computer Interaction (HCI), Industrial Design, and the Social Sciences, in the form of a case study on the design of digital touch. The case study explores this design space in the context of a User-Experience Design module at Loughborough University's School of Design and Creative Arts (SDCA), part of the BA Industrial Design and Technology (ID) programme. We outline the case study site and methodology and discuss how the study findings concerning the students' processes and outcomes led us to consider ways to bring more social and sensory-experiential sensitivities to their design process. In order to enhance students' consideration of the social and sensorial aspects of touch in the Experience Design process, we suggest educational design tools are needed to encourage consideration of touch, the fuller exploration of opportunities to design new ways of feeling, and situated reflection regarding the meaning and value of touch, and outline the early stages of our development of the Designing Digital Touch Toolkit as one such tool.

First, we contextualise the case study in relation to recent changes in HCI, ID, and HCD education, with attention to experience prototyping and storytelling as core to design pedagogy.

The Shifting Backdrop of HCI Education

The boundaries of the disciplines of HCI and ID are undergoing rapid change. We have seen the expansion of HCI beyond its roots within human factors and cognitive psychology where efficiency and usability were paramount, through a time where the hedonic aspects of interaction were acknowledged but still bolted on (Blythe & Monk, 2018), to today where design of experiences is now the '*central and explicit*' object of design (Harrison, Sengers, & Tatar, 2011; Hassenzahl, 2018). This has coincided with similarly seismic shifts within ID practice from form giving to consideration of form and function, through Interaction Design (Moggridge, 2007), User-Experience Design (UXD) (Hassenzahl, 2005), and now Experience Design. Today's Experience Designers draw on both disciplines to not only deliver products that are useful, usable, and satisfying to use (Bevan, Carter, Earthy, Geis, & Harker, 2016), but also to operate within contexts where the boundaries between business and design are increasingly blurred (Mitchell & Melinkova, 2018), and to design systemically across multiple physical and digital touchpoints, taking the needs of diverse stakeholders into account. The materials available to designers from which to craft experiences have never been so diverse, particularly at the intersection between physical and digital materiality (Pink, Elisenda, & Lanzeni, 2016) where digital touch communications reside.

Education of tomorrow's professional designers is also taking place against a backdrop where the relationship between designers and the people they are designing for is fundamentally changing. In response to the increasingly unbounded and complex societal problems that designers are called upon to address (Sanders & Stappers, 2008), co-creation with people rather than designing for people is emerging as part of the shift from designing isolated products to designing connected and meaningful experiences. This is leading to new strategic roles for professional designers as the owners and facilitators of the design process and creators of tools and methods that allow all to participate in design. This role has been further amplified by the emergence of '*design thinking*' (Brown, 2009) which has led to HCD methodologies becoming central to technology innovation and business transformation processes, thus further democratizing design as a discipline.

UX Design Teaching

ID education has, in many national and international contexts, a signature pedagogy as students are predominately motivated to learn for a particular profession, rather than to acquire domain knowledge (Shreeve, 2015). Teaching of UXD to ID undergraduates has a similar emphasis on developing professional practice alongside the qualities needed for critical enquiry and independent learning. In the mid to late 2000's in the UK and USA, HCI teaching tended to reside predominately within computer science or psychology departments. However, the paradigm shift of HCI towards experience (Harrison et al., 2011) within industry and academia required a holistic, visual, problem-based way of thinking (Buxton, 2007) that has much in common with ID practice, with many students going on to careers within the fast growing UXD industry.

The UK Design Council '*Double Diamond*' (Design Council, 2005) is a framework that is used internationally by many within UXD teaching (and beyond) to structure student design practice. The Double Diamond describes four key stages of design common to any design practice focused on product- and service-centred innovation: Discover, Define, Develop, and Deliver (see Fig. 1.). This framework communicates the need for both divergent and convergent thinking within an HCD process. Equal emphasis is given to strategically identifying the '*right thing*' to design and then, once a vision for the future product has been established, designing the '*thing right*' (Wilson & Mitchell, 2018) through iteration of product concepts in collaboration with representative users. This is consistent with the representation of design as overlapping processes of elaboration (divergent opportunity seeking) and reduction (convergent decision making).

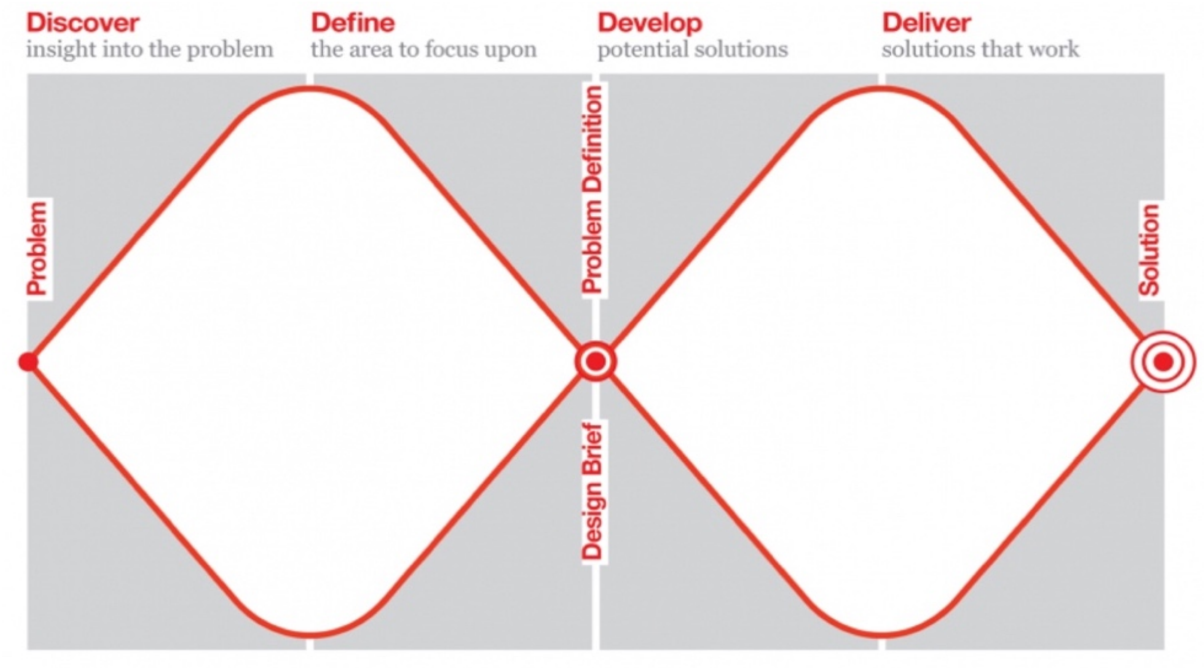

Figure 1. The Design Council 'Double Diamond' model (Design Council, 2005).

This framework underpins UXD teaching at SDCA, the site of the case study presented in this paper.

The Role of Experience Prototyping and Storytelling in UXD

The value of prototyping is well established within international design education and practice in both ID (Youmans, 2011) and HCI design (Lim, Stolterman, & Tenenberg, 2008). The benefits of prototyping within design education include increased creativity, innovation, and design synthesis skills, with a review of world leading design school curricula showing an orientation towards active learning and extensive use of prototyping (Berglund & Grimheden, 2011). Prototyping within UXD practice is often orientated towards tactical evaluation of design ideas (Hinman, 2012) with a focus upon usability, although its generative role as a tool for creation of meaning has been recognized and championed for many years (Lim et al., 2008). Buchenau and Fulton Suri (2000, p.425) first introduced the concept of '*Experience Prototyping*', defining an experience prototype as "*any kind of representation, in any medium, that is designed to understand, explore or communicate what it might be like to engage with the product, space or system*". They describe its use as a way to capture the contextual, physical, temporal, sensory, social, and cognitive factors that should be considered during the exploratory generative stages of design. Whereas Buchenau and Fulton Suri describe the technique as a way for designers to immerse themselves within a design space, largely by simulating what it would be like to be the user (also known as '*bodystorming*'), others have developed experience prototyping as a participatory design technique. This involves the acting out of scenarios within realistic contexts of use using low-fidelity props to enable the meaning of future products to be explored unconstrained by representations or concerns about how future enabling technologies may work (Iacucci & Kuutti, 2002).

The use of low-fidelity experience prototyping has been core to the development of pedagogy for UXD, providing a means to help student designers to understand that user experiences are situated and constructed by the context of use (Kankainen, 2003), and that their design and meaning should be negotiated collaboratively by designers and users (Muller, 2003). Theoretically, this approach is underpinned by the notion of embodied interaction (Dourish, 2004) at the heart of 3rd paradigm HCI (Harrison, Sengers, & Tatar, 2011). In particular, with attention to grounding the meaning and nature of interaction in the context within which it takes place and the ways that embodied meaning of interactions unfolds over time. Accordingly, user experiences should be designed and evaluated within the context within which they will be used (Sengers, Boehner, & Knouf, 2009). This requires the student designer to locate their generative and evaluative design activities out-side of the safety of the studio and collaborate with their target users '*in the wild*'.

Storytelling is a medium for constructing and conveying meaning in relation to the context of use that has become central to UXD pedagogy (Kolko, 2011). Students use narrative form to make sense of the problem space with users; to create temporal based abstractions of reality, such as experience maps, to then generatively explore future experiences, using contextual scenarios. In doing so, they move from understanding '*the world as it is now*' to exploring the '*world as it might become*' (Dubberly, Evenson, & Robinson, 2008). These scenarios then form the basis for experience prototyping (Buchenau & Suri, 2000) with target users, using constructed props and prototypes to act out choreographed scenarios within a realistic context of use. Finally, students create video-based prototypes (Yliris & Buur, 2007) of their final concepts to convey their visions for future experiences, with storytelling used explicitly to convey the '*hero's journey'* and to manifest how their future product enhances the experience of their target user.

Case Study Design and Method

The case study presented in this paper is an illustrative case study (Yin, 2009) which describes and explores the pedagogy of HCD for digital touch communication. It addresses the question, what happens pedagogically when we move '*digital touch communication*' to the centre of a HCD design process? More specifically it asks, how might current pedagogical experiences with design 'materials' and rapid prototyping shape design students' engagement with the design of digital touch experiences? And how might the speculative, social, and sensory aspects of touch experience enhance design student engagement with touch?

The case is bounded by a design brief on digital touch communication in the context of a UX Design module within the BA Industrial Design programme. It is the result of an interdisciplinary collaboration between the authors, academics in HCI and ID, and Social Science researchers on the *InTouch* project (a 5-year research project exploring digital touch communication).

Case Study Site and Participants

The case study is situated in the School of Design and Creative Arts, Loughborough University (SDCA) - a leading UK design school.[1] Specifically, a cohort of second-year students on the User-Experience Design (UXD) module, an optional module on the BA Industrial Design and Technology (ID) programme. This year was selected to provide a shared understanding and competency in UX design. Students were recruited via a face-to-face introduction to the project, they were given a detailed information sheet, and their consent was sought for participation in the study (i.e. to be observed, audio and/or video recorded). Participation was voluntary, students were able to opt in or out at any stage, and it was made explicit that refusal to participate would not affect their course experience or grading. A total of 64 full-time undergraduate students enrolled on the module participating in the study and all participated in the study. The cohort comprised of 46 students that identify as male, and 18 that identify as female.

Case Study Pedagogic Approach

The UX Design pedagogical approach at SDCA is briefly outlined here as it provided the structure for the case study design. The approach is underpinned by project-based learning (Capraro, Capraro, & Morgan, 2013) where students address over extended periods of time complex tasks based on challenging questions or problems, culminating in iterated and refined design outcomes (Koutsabasis & Vosinakis, 2012; Thomas, 2000), within the Double Diamond Design framework, outlined earlier. Low-fidelity experience prototyping is a core pedagogic method used, which has evolved over the last 8 years at SDCA, to scaffold the learning process within the storytelling medium. Studio-based workshop activities are used at key stages of a project to enable '*learning by doing*' and support cycles of experimentation and reflection (Kolb, 1984; Nilson & Dewey, 2006). Throughout the design-project, the student is on a learning pathway towards the reconciliation of two states – from the problem towards the solution (Checkoway & Schon, 2006; Tovey, 2015). By reflecting upon phenomena and their own understanding, reconciliations (concepts) are made and further reflected and iterated upon. The signature nature of this UXD pedagogy motivates the lecturers to seek out challenging assignment briefs that push students to engage with themes at the forefront of UX professional practice and societal trends. The design space of digital touch experiences and the emergence of digital touch for communication is one such theme. It is of particular relevance to the ID students because of the related intersections of physical and digital materiality, and the landscape in which their future professional careers are likely to be situated.

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[1] The Guardian (2020). University Guide 2020: League Table for Design & Crafts. Date Viewed: 17 Feb 2020. *https://www.theguardian.com/education/ng-interactive/2019/jun/07/university-guide-2020-league-table-for-design-crafts*

The Complete University Guide (2020). Art & Design League Table 2020. Date Viewed 17 Feb 2020. *https://www.thecompleteuniversityguide.co.uk/league-tables/rankings/art-and-design*

Case Study Activities

The case study design included three activities: 1) A lecture on digital touch; 2) A project brief on digital touch design; and 3) A series of three experience prototyping workshops. Each of these activities is described below.

1) *An introductory lecture* by one of the *InTouch* academics introduced the students to the notion of '*digital touch*'. Through the (45 minute) lecture, students were shown examples of a wide range of digital touch communication devices and environments, and the kinds of technologies that may facilitate digital touch communication now and in the near future. They were encouraged to consider how the digital mediation of touch had the potential to change who, what, and how people (and machines) were going to be able to touch, how they might relate to each other, and how people may come to know and experience the world differently through touch. Digital touch was broadly defined as touch that is '*digitally mediated*', and could involve a range of technological domains, including haptic devices, virtual touch applications, wearables and bio-sensing, within co-located and remote communication contexts. Communication was broadly defined as the sharing of information, feelings, sensations, skills, thoughts or ideas between humans, humans and machines, or humans and other objects. The scaffolding of students' learning and design process through the supporting lecture helped to build student confidence whilst leaving space for creativity and innovation.

2) A project brief on digital touch communication design was devised collaboratively between SDCA and the *InTouch* team and set as an assignment for the 64 second-year ID students taking an optional module in UXD. The students' assignment brief was:

> *'…to develop an innovative, future-facing digital product or service that enhances communication through touch in one of three sectors: personal relationships, leisure, or health and wellbeing. To do this, students need to first research a specific communication context that would benefit from the introduction of touch technology, for face-to-face or remote interaction. Students then need to identify specific user needs and, in collaboration with target users, develop and refine a product or service that will respond to those needs that includes an element of digital touch.'*

The brief for the product or service concept was framed by constraints that required students address a real-world problem identified through research activity and be iteratively refined through experience prototyping; define their target user group; move beyond touch screens and mobile apps; incorporate other forms of tangible interaction, existing or emerging technologies tapping into current trends, the '*weak signals*' of possible touch developments. While they could draw on other senses or modalities, touch was to be central to their design. They were also constrained by ethical considerations of safety and wellbeing, reflecting on what might be appropriate contexts and boundaries of touch. Students were introduced to the brief by the Design educators in the class, and given a paper and digital copy of it.

3) *A series of three workshops* were facilitated across the module to support the students' concept development and experience prototyping in relation to digital touch communication. Low-fidelity experience prototyping workshops were structured around 4 prompts: Question, Plan, Test, Reflect (QPTR), which the students situated in the context of digital touch communication. Students first needed to decide the question(s) that the digital touch experience prototype would be used to explore with consideration of the '*user*', '*task*', and '*environment*' (proxies for the '*motivation*', '*action*', and '*context*' of an experience (Kankainen, 2003)). Students then created a plan of how to address their question(s), guided by narrative structure, for the touch experience they wished to create through a compelling scenario using storyboards (Kolko, 2011) from the point of view of the target user. To do this they considered the roles and scenes, data required, protocols and ethics established and found the tools, props, and actors to design and produce a low-fidelity digital touch experience prototype. In the Test phase, students worked in small groups and built on the theatrical method of investigative rehearsal (Stickdorn, Lawrence, Hormess, & Schneider, 2018), a more staged variation on the bodystorming. The format followed a watch (act out the scene without interruption), understand (act out the scene again but call '*stop*' to question aspects of the experience), and change and iterate structure (act out the scene again, but this time make changes to enhance aspects of the experience). The iterated version of the scenario was captured as rough video using the students' smartphones for future development and reflection. In the final Reflect phase, students engaged with cycles of experimentation and reflection (Nilson & Dewey, 2006).

Through the above QPTR process students are not only '*doing*' but also making criteria-based judgements towards the generation of insight and original knowledge (Krathwohl, 2002). This process was rehearsed through three, three-hour studio-based workshops designed to guide the students though the experience prototyping process including: the construction of a meaningful narrative to convey their emerging touch experience design; encouragement towards touch experimentation to develop empathy with the user and their desired experience; and supportive resources for transitioning to independent learning and practice when they take their prototypes out '*into the wild*' to evaluate with users in context.

The prototyping was led by SDCA academics and supported by the *InTouch* team. These drew on rapid prototyping workshops facilitated by *InTouch* elsewhere (Jewitt et al, 2019), which provided participants with a range of sensory materials and touch words. This expansion of materials aimed to bring to the fore sensory-experiential sensitivities and to support consideration of the sociality of touch experiences, rather than focusing on only functionality, was in line with embodied interaction thinking. '*Body scaffolding*' materials, such as plain white socks, white catering hats, and white face masks (developed as an element of SDCA's experience prototyping process, and partly inspired by the all-in-black invisible '*Kurogo*' assistants of Japanese '*Kabuki*' (Cavaye, 1993)) were also provided to encourage experimentation of touch interfaces that go beyond the hand.

Data Collection and Materials

In the prototyping sessions students worked in 10 groups (of 6-7) and each researcher focused on the activity of 3-4 groups in a particular section of the room; while the lecturers worked with all groups - providing an overview of the workshops. Brainstorming activities were observed and post-it notes photographed to capture the process. Whole class discussion and demos were video-recorded using one camera. Three *InTouch* researchers used roaming video cameras to record the interaction of student prototyping with the materials and one another. They moved and occasionally 'felt' with participants, in an effort to gain insights into their experiences, and where their design processes were not clearly articulated they asked questions to probe for them. These were supplemented by researcher observations (recorded in field notes) and text-based data generated by the participants was also photographed (e.g. post-it notes, storyboards, and flip-chart notes). A total of 14 hours of video data was collected. In addition, the students' course work responses to the brief in the form of individual concept boards (64 PDF documents), and group concept videos (12) were collected.

Analytical Frame and Process of Analysis

The prototyping session observations and field notes provided a background and thematic insights for the analysis of the students' final concept boards and videos. The *InTouch* team reviewed and conducted a thematic analysis of the 64 student storyboards and video prototypes. We reflected on the kinds of design concepts that had emerged and how the digital-touch-centred brief shaped the design process and located the students' concepts in the emerging landscape of digital touch. Our approach to the analysis was guided by both multimodal and sensory ethnographic sensitivities. This led us to explore how students engaged with the materials made available to them and the potentials of experience prototyping to speculate and engage with the social and sensory aspects of touch experience design. Through team discussion of the workshop experiences, and preliminary analysis of the students' concepts boards and videos a set of analytical categories were developed with which to review the students' work: a) the overall design concept – the problem space of touch; b) the technology type and features used (e.g. bio-sensing, wearable solutions); c) the character of the touch communication supported by the design – the what, who, when and why of digital touch; d) the character of the communication afforded via digital touch – its temporality, spatiality, share-ability etc.; e) how the body was brought into the interaction – where was touch located on or in the body; f) how touch was related to other senses or modes; g) an overall assessment as to whether the designed digital touch served to supplement, heighten, extend, or reconfigure touch experiences. Through these questions, we explored the touch narratives underlying the student designs.

The analysis of the concept boards provided a route back into relevant video recorded episodes of prototyping to explore the case study research questions through attention to the interactions between students and materials and the design of digital touch communication.

Findings and Discussion

The focus of this paper is on the pedagogy of '*digital touch communication*' within HCD design processes, however, we first provide an analytical overview of (64) students design concepts to situate the discussion of how pedagogical experiences with design 'materials' and rapid prototyping might shape and enhance design students' engagement with touch, notably its speculative, social and sensory aspects, and our call for new educational '*tools*' for the learning and teaching of design for digital touch experiences within a User-Experience Design context.

Overall the students' design concepts imagined a functional problem space for touch. The majority centred around touch (mainly as vibration) as a means to convey connection and/or presence. These designs entered existing 1-2-1 relationships (e.g. parental, romantic), or professional-care to provide support with anxiety, homesickness, loneliness or health and well-being (including sports injury). Some example concept devices included, a touchable-bed-side lamp, set out to managing the emotion of adult child-parent separated using touch as non-verbal presence/connection; the social potential of touch to enhance connection including, a virtual-reality environment that haptically connected remote players; several devices enabled a tactile sense of connection (mainly via a phone app) with pets, as well as animals in the zoo. Touch was strongly linked to ameliorating the anxiety of being connected and providing a sense of control over self and your touch-environment (e.g. the management of claustrophobia, reducing 'first date' anxiety, creating a touch-free 'your personal bubble' in a busy workplace, to alerting cyclists of approaching cars). This notion of digital touch as control and 'solution' was extended to safety, and the provision of touch feedback and monitoring as reducing risk (e.g. in relation to the elderly 'falling'; cycling and motorbike riders; personal safety on nights-out; and accidents and injury more generally).

Touch (in the form of bio or motion-sensing, and vibration) was used by students as a kind of tactile corrective punishment and to promote Kinaesthetic awareness. For instance, many of the students' design concepts imagined the use of digital touch feedback to re-shape the body or a bodily-technique, sensing feedback, or temperature re-calibration, disciplining the body through touch into an idealized body. For example, a device worn on the user's wrist would vibrate if they spent too long on their phone or to encourage the correct grip of a tool. Vibration featured in many designs to enhance navigation, for instance, a device for visually impaired people warn behind ears which change pitch according to the degree change in direction; a tactile smart cane with vibration; and a motorbike helmet with vibration alerts. Finally, touch was brought into the domain of efficiency and convenience in many of the design concepts for instance making the controls of an electronic guitar more accessible in a timely way that made bodily movement more efficient, or health analysis in time-efficient ways.

Digital touch was generally conceptualised as touch between a monitoring device and the wearer. The types of technology and digital features used by students in the concept designs were strongly shaped by those 'preconditioned' prototyping: mobile phones, Apple watches, digitally imagined auxetic materials, heat pads, VR, AR, smart textiles, connected devices, bio-sensing, GPS, environment sensors, a wide range of digital wearables, smart socks, and other pre-existing garments. Despite this wide range of technologies, most concepts limited digital touch to some kind of vibration, and the role of touch to functional aspects - activation, feedback, and sensing. The student concepts suggested that they also grappled with the notions of input/output and sending/receiving in relation to touch, and how this happened was not always clear.

The what, who, when and why of digital touch was thus limited, often tied to the mobile 'screen' – reimagined onto the body, or another device, with buttons and alerts a constant feature. The difficulty of moving beyond standard digital touch forms, swiping, tapping, vibration, and the use of touch as 'activating a feature' dominated the case study. Even when digital touch was degraded and reduced to a vibration, however, touch was talked of as gentle, weak, firm, too strong, holding, caressing, nice, unpleasant, a stroke, or a hug. It was attributed with some social meanings, such as caring touch, comforting, playful, rejecting, loving, supportive, or controlling touch. Digital touch was seen as having the potential to fulfil social needs, with 'the right amount of touch' being key, understanding when pressure and duration moved from supportive to 'too much' through to 'aggressive or violent'. For some participants, interpretations of touch involved gendered associations and the creation of masculine and feminine touch, which attributed technology itself with a gender.

The character of the communication afforded via digital touch, its temporality, spatiality, and share-ability was a feature of some student design concepts. Participants in the case study explored technological, social, and emotional temporal features of touch to structure communication experiences through their prototypes. These were shaped through their experiences of mobile media/apps in terms of communicational time-effort, spontaneity and managing response time, and obligations and expectations. The student concepts also raised issues regarding the temporalities of touch including on/off touch, always on touch, being triggered by specific touch, and some afforded synchronous touch, while others enabled asynchronous touch.

The sense that the body is vulnerable through touch communication resonated across the case studies. The student design concepts reflected the social norms of touch, with over a half locating touch on the hand or arm. While some engaged with other body parts, only a few engaged touch with the whole-body. Bodily feedback along particular digital-material parameters was key in students' imagination of digital touch concepts; here, bodies were nudged into specific positions and kinds of movements, and bodily feelings, states and symptoms were reinterpreted through numbers, vibrations, and emotion displays. More broadly, the concepts primarily situated touch in relation to ideal normative bodies, that is fit and healthy (though some temporarily injured through sport), available, and (with a few exceptions) able-bodied. The dominance of mobile apps and wearables (often the two were linked) also suggested a design conceptualisation of the body as a future touch interface. The student concepts primarily engaged with touch in the context of the visual, and aural senses. Overall, their designs of digital touch served to supplement or heighten and amplify existing touch experiences, rather than designing digital touch possibilities that extended or reconfigured touch experiences in new ways.

Towards a UXD Pedagogy for Designing with Digital Touch

In reflecting on the students' workshop activities, storyboarding, prototyping, and subsequent concept development, we were struck by the relative conservatism with which the design students approached the brief. The quest for technological solutions appeared to override considerations of the sensory-experiential and social aspects of the products and services they designed for. We illustrate this below by focusing in on one example typical of the students' relationship with prototyping materials, before turning to the broader pedagogical implications.

The materials were introduced to the ID students in the first of three workshops (see Fig. 2.), designed to support ideation of initial '*sketchy*' concepts, before experience prototyping one or more of these concepts using the QPTR process. The premise was that at this divergent and creative stage of the UXD process (the 'Develop' stage of the Double Diamond) exposure to a wide variety of sensory materials would provoke the students to consider a broad range of touch-mediated communication experiences.

Figure 2. Sensory materials used within the workshop.

The student participants were, however, unexpectedly '*hands off*' and uninquisitive about the sensorial qualities of the materials. This was despite being encouraged by the lecturers and the brief to explore and play with them and consider their affordances as they collaboratively progressed their early concept ideas. Whilst the students enthusiastically engaged in the experience design process, scaffolded with the QPTR framework and storytelling activities (described earlier), their engagement with the sensory materials was predominately in the context of seeking out and constructing props to support acting out and exploration of concept ideas through storytelling. Their final concepts created in response to the brief similarly foregrounded application of digital touch technologies to deliver novel product features, with less reflection on the social meaning, ethics, and role of touch interactions within their imagined future experiences.

The markedly low-level of engagement with the sensory workshop materials was surprising (as compared to those with speculative design students led by *InTouch*, for example, see Jewitt et al, 2019). This led us to reflect more broadly on the role of prototyping materials within UXD and the implications for HCI teaching. This issue is particularly relevant where the current signature pedagogy of Experience Design is evolving to meet market demands for graduates equipped to think systemically whilst designing at the intersection of digital and physical product design.

The ID students undertaking the optional UXD module had developed a relationship to physical, solid materials (wood, metals, plastics etc.) in line with the traditional teaching of their discipline, where knowledge about material properties is developed somewhat separately from their application. Students are encouraged to understand material science data, such as the Young's modulus of steel or the thermal properties of silicon, or possible finishes, treatments, and coatings towards the technical and visual resolution of their proposal, rather than the social and sensorial qualities of these materials. In response to exploration of the problem space (Discover) and generation of key insights and opportunities (Define), concepts are typically sketched on paper, with rapid ideation encouraged to explore a variety of forms and functions before moving to low-fidelity prototyping using blue foam or card, and then switching to CAD and increasingly 3D prototyping to further refine the design. In that scenario, whereas consideration of the feel and properties of materials may be encouraged, it is subservient to considerations of form and function within this iterative but ultimately reductionist process of moving from problem to solution. This case study, and SDCA UXD pedagogy more generally, although prioritizing the design of experiences over products and more divergent exploration of problem and solution spaces, appears to lead to a similarly reductionist relationship with materials and technologies. Similar to the refinement of sketches and prototypes from low- to high-fidelity, within UXD, scenarios are used to mediate between problem and solution with increasingly detailed narratives and visualizations used to advance the fidelity of ideas towards the final solution. Students are initially encouraged to ideate concepts using sketchy contextual scenarios to narrate experiences at a behavioural level, deliberately omitting the details of user interfaces to keep the story focused on conveying the desired experience, undistracted or constrained by the detail of specific interactions.

At the concept ideation stage where we introduced the sensory materials, the students' pedagogic training therefore led them to prioritize rapid and divergent ideation of solutions as they acted out different contextual scenarios and questioned aspects of the experience through bodystorming with quickly constructed experience prototypes. Although the role of mediated touch communication was often central to their bodystorming experiments, the sensory nature of the interactions was not fully utilised as a design resource, as students focused on crafting the narrative of their proposed future experience. For example, Fig. 3. and Fig. 4. show students exploring the role of digital touch communications within an experience designed to help amateur golfers adopt the correct posture when practicing their swing.

Figure 3. SDCA students experience prototyping.

Figure 4. Exploring the role of digital touch within a golfing context.

Experiments with different forms of digital touch are apparent (a surgical glove is being used as a prop to signify a smart glove that senses the golfer's grip on the club; string and a balloon are being experimented with to explore how pressure on the back and/or shoulders could be used to direct the golfer into the correct posture as part of a shirt-based wearable). Although the nature of the sensations conveyed was discussed and negotiated amongst the student designers, this was '*broad brushed*' typically at the level of '*inputs*' and '*outputs*' (e.g. the thumb of the glove could vibrate to alert you [the golfer] that the grip is correct and you can begin to swing). Digital touch here was mainly concerned with the translation of binary information towards a yes/no user relationship with the concept. Are my shoulders situated correctly in relation to the activity? Is my arm positioning correct? Touch in this concept becomes a mechanism to convey objective correctness – an extension of the designer's intent to make a perfect solution to a problem - as opposed to enhancing the experience with subjective quality (e.g. wrong but with a reaffirming touch vs wrong with an aggressive touch). An experience is present and can be refined and iterated, but its parameters are narrowed to the experience of engaging with the information, not the qualities of touch *per se*.

The sensation of touch or situated meaning of touch in this context, and as seen across this workshop, was not articulated (e.g. a '*sharp touch*' or '*angry touch*'), touch was not foregrounded or its meaning critically explored. Reflection was present in the action and iteration of the ID students, however, the character of problem reconciliation narrowed the scope of the students so as to omit directions and ideas that did not support a tangible direction forwards within the safe confines of their training-to-date. Reflection here became a tool for goal-orientated resolution within the parameters of a more novice comprehension of meaning and criteria-based judgements (Krathwohl, 2002). Judgements were not made in light of an expansive '*what if…*' proposition that would indicate higher order understanding and an ability to deal with ambiguity. The students were trying to emulate the processes taught to them, with learning objectives concerned with being able to consolidate and replicate the procedures and display the level of comprehension expected of a second-year undergraduate ID student, not to innovate and create new knowledge.

This emergent UXD practice for designing with touch is in line with established UXD pedagogy, particularly how contextual scenarios are used to explore behaviour and the narrative of experiences before the details of user interfaces and (typically screen based) interactions are resolved. How students go on to articulate the sensory interactions once the overall narrative of the experience has emerged has yet to be resolved. Nonetheless, it is significant that studio-based and staff-supported experience prototyping provided the ID students with the knowledge and confidence to take these prototyping techniques out into the wild to further resolve their designs with target users later in the assignment (for example, Fig 5.).

Figure 5. Later experience prototyping of iterated touch technology concept in context with a user.

Future Work: Educational 'Tools' for UX Design Learning and Teaching of Digital Touch Experiences

This case study gives a sense of the complexity of engaging novice designers in the task of imagining digital touch futures. It can bring forth utopic and dystopic visions, and easily reproduce cliché and stereotypical visions of digital touch that fail to engage with its nuanced social and sensory aspects or speculative futures (Dunne and Raby, 2013) of extended and reconfigured digital touch. The case study, tracking and observing the students' design process (ideation, experience prototyping, and concept development), highlighted the difficulty of imagining the sociality of digital touch and moving beyond the constraints of dominant digital forms in the current landscape (e.g. mobile phone apps, and on-the-wrist-wearables).

The case study suggests that there is a need for new educational 'tools' to support and scaffold both the learning and teaching of design for digital touch experiences within a User-Experience Design context. Design students need support to approach digital touch technology as a way of enabling novel user experiences that significantly extend or enhance existing ones and move towards a socially orientated reconfiguration of digital touch. More specifically, resources are needed to support students to: go beyond technology-driven solutions and stereotypical touch sensations (vibration); place more emphasis on the sensory and communicative properties of touch throughout the design process; encourage greater critical awareness, discussion, and investigation of touch at different stages of the design process; reflect on what touch could mean within user experiences, different types of touch, what touch might mean and feel like in different contexts; and to engage with the whole body, bodily sensations and social and cultural boundaries of touch.

In response, we have used the case study findings to inform the development of a prototype Designing Digital Touch toolkit - with specific reference to the sticking points students experienced in their engagement with materials and the process of prototyping touch, and analytical themes that emerged across the student design concepts, and the case study more generally. The toolkit is a card-based resource designed to open up and articulate the sociality and sensorality of touch into the UX design space, and guide the user by providing new and divergent routes into their imagining of digital touch futures. It draws on and extends the Double Diamond Design model by proposing a 'Pre-Discover' phase which focuses on explorations of and sensitisations towards 'touch' as it manifests itself in a range of social and embodied contexts. There are three types of cards for each design stage which aim to put touch and its possible digital mediation at the forefront of students' thinking and making. 1) *Filters*, that is, contextual questions to help participants reflect on their own and others' experiences (e.g. When does it matter who touches? How do you touch to communicate? How visible is your touch?). 2) *Activities*, that is, structured exercises and explorations (e.g. List and discuss five objects you touched today; Find some materials you wouldn't usually work with and explore how each would change your design; Map how touch has appeared and disappeared in your design process). 3) *Wild Cards*, that is, abstract provocations for thought or action (e.g. Touch meaningfully; Amplify the touch; or Make it soft). The toolkit prototype is currently being tested and evaluated by design students across a range of design courses.

Conclusion

We have described how we moved '*digital touch communication*' to the centre of a UX Design module and what happened pedagogically. We have shown how current pedagogical experiences with design 'materials' and rapid prototyping shaped design students' engagement with the design of digital touch experiences, with attention to how they conceptualised the problem space of touch, touch-based technologies, the potentials and character of digitally mediated touch for communication, and how the sensing body was brought into their experience prototyping and design concepts. The case study workshops confirmed the potential of using low-fidelity prototyping to rapidly explore and prioritize considerations of experience, rather than the capabilities of technologies as part of a UXD process unfettered by the time taken to construct technology prototypes or knowledge of how to do so. However, we found the students' design approach to digital touch was at times constrained by an orientation to the functional and technological aspects of touch, rather than with the speculative, or social and sensory aspects of touch experience. This limited the design of digital touch to mimicking, supplementing or amplifying existing touch experiences. Whilst the ID students did not fully embrace the opportunity to explore different social and sensory experiences or to consider their meaning within future digital touch communications, their engagement in the workshops does reflect their expected knowledge of ID and UXD practice at the expected point in their education. This highlights a gap in knowledge raised by this work that can be broadly framed around how to consider the sensory meaning of interactions within a structured design process and points to an area worthy of further development within these signature pedagogies.

Finally, we have made the case for educational tools for designers which would enhance the construction of meaning at all stages of Experience Design (broadly framed by the Double

Diamond) and to encourage further situated reflection regarding the meaning and value of touch. We have proposed one such tool in the form of the Designing Digital Touch Toolkit, a research-based resource in development by the authors. By seeding understanding of the nature and meaning of touch in an accessible and relevant form, we argue that students can be scaffolded and encouraged within the learning and teaching of the HCD process to more fully explore opportunities to design new ways of feeling rather than '*bolting on*' considerations of touch once the problems to be solved have been defined. The related intersections of physical and digital materiality, and the emergence of digital touch in the design landscape in which students' future professional careers are likely to be situated makes this paper particularly significant for the UX and ID pedagogic community.

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A Biomimetic Design Experience in Informal Interior Architecture Education

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Abstract
Biomimetic design is the process of creating innovative ideas inspired by nature. This approach adapts processes of natural organisms to solve design problems and guides design in interior architecture, similar to many other disciplines. This study aims to present the process of implementing the biomimetic approach to interior architectural design in an informal education environment and to discuss the outcomes of this experience. In this context, the approach and implementation methods of biomimetic design have been examined and a workshop study called "BIOStructure", which was intended to integrate these methods into spatial design, has been analysed. This workshop was organized as part of an International Student Triennial in order to experience the approach of biomimetic design as an informal education tool. In the workshop, students were asked to experiment with biomimetic design in either a solution-driven approach, or a problem-driven approach. As a result, it was observed that most of the students preferred a solution-driven approach to a problem-driven approach and students in earlier stages of design education tended towards form-oriented abstraction of biological knowledge, whereas students with more design experience tended towards principle-oriented abstraction.

Keywords
biomimetic design; interior architecture education; biomimicry; design education; informal learning; workshops

Introduction
Biomimicry is an applied science that is the source of inspiration for solving human problems through the study of natural organisms, processes and systems. The use of nature as a source of inspiration to develop new concepts for human conceived systems has occurred throughout human history. Systematic studies of how biological knowledge can improve the generation of ideas are relatively new (Salgueiredo, 2013). The term "Biomimicry" (bios: life, mimesis: imitation) was coined in 1962 by the naturalist Janine M. Benyus. Benyus describes Biomimicry as "*The conscious emulation of nature's genius*" (Benyus, 1997). Another definition of Biomimicry is "*Mimicking the functional basis of biological forms, processes and systems to produce sustainable solutions*" (Pawlyn, 2011).

Designers take inspiration from various sources to solve challenging design problems. Nature is an important source of inspiration for scientists, designers and engineers from different fields of interest. Every organism in nature is unique and fully adapted to its environment. This lasts through generations, while passing the test of survival to reach its next generation (El-Zeiny, 2012). Disciplines such as architecture, construction, information processing, robotics, etc. use bioinspiraton for generating new ideas (Speck, Speck, Beheshti & McIntosh, 2008). Similar to other design disciplines, various biomimetic design methods have been developed for the discipline of interior architecture. In this research, a literature review was previously conducted on the methods that designers and interior architects who want to use biomimicry could use to improve the built environment. The workshop experience realized with the help of the determined method as a result of this review has been shared, and the students' feedback related to the biomimetic design process has been evaluated.

Biomimetic Design Approaches

Biomimetic design is an emerging research field in design that seeks for systematically mining biological knowledge to solve design problems (Stone, Goel & McAdams, 2014). This approach has inspired many designers in the history of design. However, it is relatively new that it has become a movement by the growing need for sustainability and desire for creativity and innovation in design (Goel, Vattam, Wiltgen & Helms, 2014).

The literature review on the biomimetic design approach demonstrates that the approach has a bidirectional design process (Zari, 2007; Helms, Vattam & Goel, 2009; Speck et al., 2008; El-Zeiny, 2012; Salgueiredo, 2013; Helfman & Reich, 2016; Nkandu & Alibaba, 2018; Farel & Yannou, 2013). These two directions could be cited such as "solution-driven" (also named the bottom-up or biology push) approach and the "problem-driven" (top-down or technology pull) approach (Salgueiredo, 2013). Starting from solution (biology) and ending with problem (technology) or vice versa, at the end, knowledge is being transferred from biology to technology to solve technological problems (Helfman & Reich, 2016). (Table 1)

Table 1. The steps of solution-driven and problem-driven approaches (adapted from Salgueiredo, 2013)

Solution-driven approach		Problem-driven approach	
Starting Point	Fundamental research (biologists)	Starting Point	A design problem
Research	Understanding the biological model	Search for Analogies	Analogy search in biological knowledge
Principle Extraction	Identification of principles in biological models	Selection of suitable principles	Suitable principles of one or more biological models analysed
Abstraction	Transforming the biological principle in a "solution-neutral form"; reframing the solution for designers'	Abstraction	Transforming the biological principle in a "solution-neutral form" and reframing for designers' understanding

	understanding of the potential for technical implementation		of the potential for technical implementation
Development	Technical implementation of the biological principle extracted	Development	Technical implementation of the biological principle extracted

Solution-driven approach
In a solution-driven approach, the biologist determines the behaviour, functions and other characteristics of biological knowledge and the designer designs for an existing need; thus biological knowledge influences human design. The advantage of this approach is that the knowledge of biology may influence the design in ways other than the predetermined design problem. The disadvantage is that a comprehensive biological research should be conducted and then the information gathered should be determined as relevant in a design context (Zari, 2007). Biologists and ecologists should therefore be able to know the potential of the research in the innovation of design implementation (El-Zeiny, 2012).

Problem-driven approach
In a problem-driven approach, where designers look to the living world for solutions, designers are required to identify problems and then biologists are to match these to biological systems that have solved similar issues (Zari, 2007).

The steps for solution-driven and problem-driven approaches are demonstrated in Table 1. In the former, the research of biological phenomena reveals some interesting property that could be useful for design applications and in the latter, a design problem triggers the quest for biological solutions that could be helpful for solving the problem. In both cases, inspiration from nature is seen as a transfer between biology and design fields for generating ideas (Salgueiredo, 2013).

Biomimicry Levels and Abstraction Stage in Design Process

Biomimicry Levels
Benyus (1997) divides solution-driven and problem-driven approaches into three levels of mimicry, namely Form (Organism), Process (Behaviour) and Eco-system. They provide a framework for designers to determine which aspect of “bio” to “mimic” (Zari, 2007). The first level of biomimicry is the mimicking of natural form. This type copies an organism for its morphological attributes like its components, materials or visual shape (Arslan, 2014). The second level is to mimic the natural processes. The behaviour level involves imitating how an organism interacts with its environment in order to design a structure that it can fit in the surrounding environment (Nkandu & Alibaba, 2018). The third level is the mimicking of natural ecosystems. This involves more complex processes than the first two levels. To

imitate ecosystems requires considering not only the designed object but also how it affects explicitly and implicitly its environment (Arslan, 2014). (Table 2)

Table 2. Levels of biomimicry and aspects examples of levels (adapted from El-Zeiny, 2012)

Form (Organism)	Process (Behaviour)	Eco-system
Formal attributes include colour, shape, transparency, etc.	Survival techniques	Response to climate by cooling, heating and ventilation solutions
Structure, stability	Collaboration and Teamwork	Waste management
Morphology, anatomy, patterns	Communication	Adaptation to various light and sound levels, self-illumination, shading, etc.

Abstraction Stage in Biomimetic Design: "Principle-Oriented Abstraction"/"Form-Oriented Abstraction"

Biomimetic design is a specific type of "design by analogy" based on analogies of nature. Designers, who attempts to implement biomimetic design by analogy, face a number of challenges (Linsey & Viswanathan, 2014). Biomimicry levels are used to build analogies in the idea generation stage of the design process. Analogies involve the use of similarities between different situations to transfer knowledge across concepts and domains for problem solving (Salgueiredo, 2013). During the abstraction stage of a biomimetic design process, the relation between biology and technology is built and the biological system is presented in the context of analogical reasoning. The transfer of knowledge is realised from a model of a biological system to a model of a technological system. This model should explain how the problem is solved in biology, and may contain references to functions, behaviours or design principles in case they are related to the solution (Helfman & Reich, 2016). Stone et al. (2014) classify inspiration through the forms of nature in three different types such as *visual*, *conceptual* and *computational*. In *visual inspiration*, pictures or other visuals of a biological system are used to create the design sharing the same visual appearance. In *conceptual inspiration,* the use of the knowledge found in biology forms design principles. *Computational inspiration* is searching through nature to find algorithms as evolutionary computation (Stone et al., 2014).

The abstraction stage is the core of the biomimetic design process. Abstraction is the stage of refining the biological knowledge to some working principles that explain the biological solution and could be further transferred to the end-design (Helfman & Reich, 2016). According to Santulli & Langella (2011), "bio-inspiration" is not a formal imitation of the natural geometry (biomorphism); in contrast, it implies transferring new strategies inspired by the natural systems to the culture of design, via an abstraction stage. In biomimetic design, "principle-oriented abstraction" of biological knowledge (organism, process or eco-system by conceptual or computational inspiration), rather than just "form-oriented abstraction" (by visual inspiration), appears to be one of the most difficult challenges. In the field of interior architecture, biology is commonly used as a library of shapes or decoration (Art Nouveau, Jugendstil), however, imitating or being inspired by natural-looking forms without abstraction stage is not biomimetics (El-Zeiny, 2012). Rossin's study (2010) asserts that interior architecture practice should "biologise" design problems by using time-tested principles of nature in the design process as a source of inspiration (Rossin, 2010). This means that, in order to be biomimetic, a design must be informed by nature's science, not just its appearance (El-Zeiny, 2012).

Implementation of Biomimetic Design Methods in Informal Interior Architecture Education: BIOStructure Workshop

The ways of using the biomimetic design approach as a tool to solve design problems have been investigated in design disciplines as well as in design education. Using a biomimetic design approach for generating innovative ideas requires the students to acquire new educational tools, and an increased collaboration between the disciplines. This would enable the students to receive some information from other disciplines, and to apply this knowledge to the design problem (Santulli & Langella, 2011). Bioinspired design experiences in architectural design education provides also an introduction of students to alternative design methods and multidimensional thinking (Yurtkuran, Kırlı & Taneli, 2013). In this context, in order to experience biomimetic design with design students, a workshop organization has been preferred as an informal learning environment facilitating flexibility, collaboration and creativity rather than a formal education environment (Karsli & Ozker, 2015).

Workshop Structure

BIOStructure workshop was conducted as part of the student triennial activities in Istanbul, with 18 participants studying in interior architecture, industrial product design and architecture undergraduate programs. The coordinators of the workshop were interior architecture department members. The purpose of these workshops was to experience the process of generating innovative ideas by imitating nature. The workshop involved the biomimetic design of a lightweight pavilion that defines an urban space, mimicking nature or a natural process, and concretization of the design idea by the models. The participants were free to select the function of the pavilion and to work individually, or in groups during the idea generation and model making stages of the workshop process. The two-day workshop achieved an intense, and productive working environment.

Learning Expectations

Learning expectations that have been envisaged for the workshop are:

- To be able to use biomimetic design approaches in solving design problems,
- To get acquainted about how to access similar problems observable in nature, to list possible biological systems and analogies,
- To be able to establish appropriate analogies between design problems and problems in nature, and to adapt the solutions in nature for the solution of the design problem,

- To be able to develop innovative solutions that meet the physical, behavioural and technical requirements of the design problem by using biological references as inspiration.

Seminar

The first step of the workshop involved a seminar held by the coordinator on biomimetic design approaches. The students were briefed on the definition of biomimetic design, related research fields, definition and steps of solution-driven and problem-driven approaches, levels of biomimicry, aspects examples of these levels, abstraction stage and biomimetic design practice cases. The seminar provided students with design clues and engaged a sharing environment.

Design Process

Following the seminar, the design problem was submitted to participants: "design of a lightweight pavilion defining an urban space, through biomimetic design approaches". The students were asked to start the biomimetic design process by selecting either solution-driven or problem-driven approaches, before research and creating design scenarios stages. At this point, a design guide consisting of steps to be followed for two approaches was submitted to the students (Table 3,4). After the design approach decision, the participants did research on the internet for the natural organisms/ecosystems or processes to imitate and drew sketches based on the scenarios they developed (Figure 1, 2). The research assignment required students to prepare a digital presentation on biological references they selected, and on the types of behaviour these references engaged in adapting to their respective climatic, geographical and physical conditions.

Table 3. Biomimetic design guide through solution-driven approach

Solution-driven approach
Step 1: Determination of nature-based solution: Identify the natural object or process that influences you by any aspect of nature: (for example: Spider web for flexibility; micro strips of shark skin for surface resistance of water, clam shell for durability, etc.) Specify the natural object or process to imitate:
Step 2: Defining nature-based solution: Investigate how the natural object or process has this feature. (For example: The silk yarn produced by spiders, which is smaller than one thousandth of a millimeter in diameter, is five times stronger than the steel wire of the same thickness and can stretch up to four times its own length. This conveying system allows the spider to build up a wide area of web without compromising its durability.) Specify how the natural object or process has / produced this property:
Step 3: Abstraction of principle: Adapt the way the natural object or process acquires this feature to the pavilion design: (For example: developing a structure solution using the microscope images of the spider web)

Include images of the natural object or process you will emulate: Specify which aspect of the natural object or process you will imitate to reflect on the design (form, material, technology, etc.):
Step 4: Defining the problem: Specify the feature and the function of the pavilion you will design by imitating the natural object or process that you selected: (For example: modularity, flexibility, durability, lightness, waterproofing, self-cleaning, breathing, self-generating, transparency, interchangeability, camouflage, self-luminescence, recyclability, structure / stability, mutation according to need, portability, easy maintenance and repair, etc.) Specify the feature that your pavilion will acquire as a result of the biomimetic design process: Specify the function of the pavilion:
Step 5: Application of the principle Submit sketch drawings of your design. Select modelling materials according to your design idea. Prepare model of the pavilion on A3 base (scale: 1/50)
Information about group members: **Name/ Surname:** **Student's grade:**

Table 4. Biomimetic design guide through problem-driven approach

Problem-driven approach
Step 1: Identification of the problem: Specify the function and the feature you want to have the pavilion you will design (For example: modularity, flexibility, durability, lightness, waterproofing, self-cleaning, breathing, self-generating, transparency, interchangeability, camouflage, self-luminescence, recyclability, structure / stability, mutation according to need, portability, easy maintenance and repair, etc.) Specify the function of the pavilion: Specify the feature of the pavilion:
Step 2: Looking for nature-based solution: Identify the natural object or process that successfully possess or produces the selected feature in nature: (For example: spider web for elasticity; microstrips of shark skin for surface resistance of water, clam shell for durability, etc.) Specify the natural object or process to imitate:
Step 3: Defining nature-based solution: Investigate how the natural object or process has this feature. (For example: The silk yarn

produced by spiders, which is smaller than one thousandth of a millimetre in diameter, is five times stronger than the steel wire of the same thickness and can stretch up to four times its own length. This conveying system allows the spider to build up a wide area of web without compromising its durability.)
Specify how the natural object or process has / produced this property:

Step 4: Abstraction of principle:
Adapt the way the natural object or process acquires this feature to the pavilion design: (For example: developing a structure solution using the microscope images of the spider web)
Include images of the natural object or process you will emulate:
Specify which aspect of the natural object or process you will imitate to reflect on the design (form, material, technology, etc.):

Step 5: Application of the principle
Submit sketch drawings of your design.
Select modelling materials according to your design idea.
Prepare model of the pavilion on A3 base (scale: 1/50)

Information about group members:
Name/ Surname:
Student's grade:

At the end of the first day, all the sketches pinned on the idea wall and digital presentations were presented by the students to the whole group. In this presentation, the students explained the steps they followed in line with the design guide, their design approach preferences, the biological reference and which feature of this reference they used for bio inspiration, how they adapted this reference on the pavilion, and the scenario of function they determined for this pavilion. After a peer review process, the first design ideas were approved. The students were asked to bring materials for model making on the following day. The second day, models of the designs were made on the scale of 1/50 (Figure 3,4). During the model making, the designs were re-evaluated and initial ideas were constantly developed.

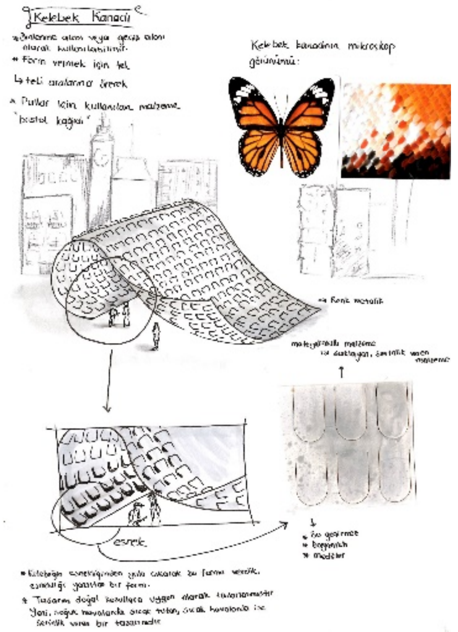
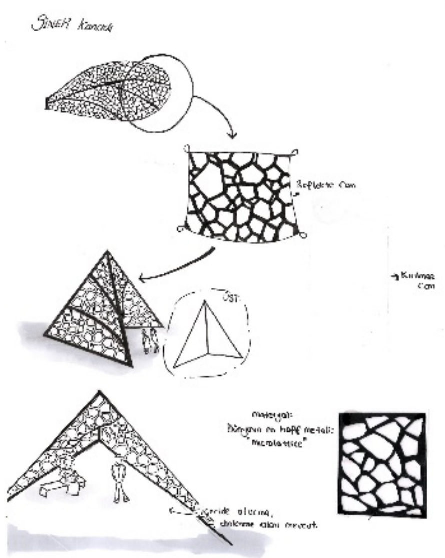



Figure 1, 2. Biomimetic design scenario sketches

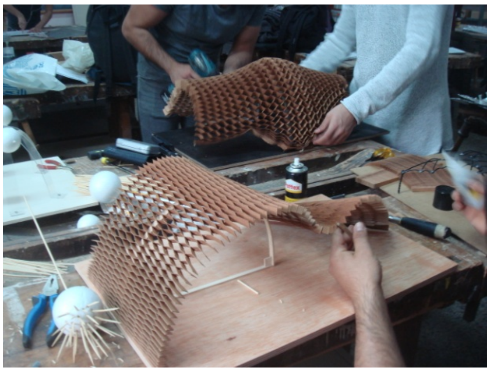



Figure 3,4. Workshop model making process

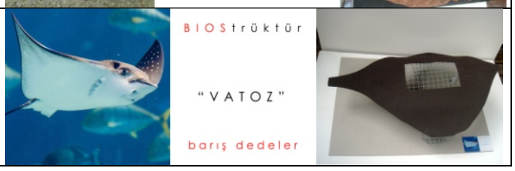
Final Peer Review

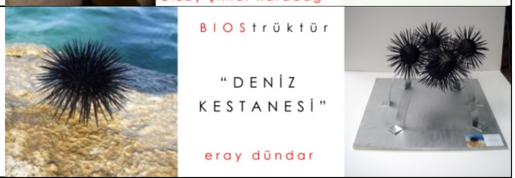
The workshop ended with student presentations. The students shared the steps of the design approach they used, the biomimetic design process and the problems they faced during the process with the whole group. Design solutions were evaluated by a final peer review. The models were prepared for the exhibition and the workshop session was closed by sharing suggestions for future studies.

Results and Evaluation

BIOStructure workshop's primary aim was to experience the implementation methods of biomimetic design and integrate these methods into spatial design. Another aim of the workshop was to examine the problems faced by the students in the design process, to investigate the students' design approach preferences, abstraction orientations and the relationship between these issues and the level of design experience of the students. Design guide notes of participants, field notes and periodic interviews during the workshop were used for data gathering. A table was prepared based on the design guide notes and images of models built during the workshop (Table 5).

Table 5. Biomimetic designs and design approaches of the workshop

Natural organism/ Process/ Ecosystem imitated	**Post-imitation characteristic of the lightweight pavilion**	**Solution-driven/ Problem-driven design approach**	**Principle-oriented / Form-oriented abstraction**	**Stdt. Grade**	**Inspirational image / Model of the lightweight pavilion**
Cobweb	Flexibility	Solution-driven	Principle-oriented	3	
Radiolaria	Expandability/ Lightness	Solution-driven	Principle-oriented	3	
Butterfly wing	Flexibility	Solution-driven	Principle-oriented	2	
Coral	Durability	Problem-driven	Principle-oriented	1	
Webfoot	Flexibility	Problem-driven	Principle-oriented	3	
Fly wing	Transparency/ Lightness	Solution-driven	Principle-oriented	2	
Isopod	Durability/ Flexibility	Solution-driven	Form-oriented	1	
Ray	Electricity Generation	Solution-driven	Principle-oriented	4	

Albatross	Wingspread	Problem-driven	Form-oriented	1		
Synapse	Establishing Point Links/ Structure	Solution-driven	Principle-oriented	4		
Fish Scale	Sparkling	Solution-driven	Principle-oriented	4		
Mushroom	Soft Tissue	Solution-driven	Form-oriented	2		
Sea Urchin	Durability/ Lightness	Solution-driven	Form-oriented	1		
Tortoise Shell	Durability	Solution-driven	Principle-oriented	4		
Bat Wing	Lightness	Solution-driven	Form-oriented	1		

At the end of the workshop, final designs were examined to see participants' preferences related to type, feature and aspect of bio-inspiration model to reflect to their design. The results are listed:

- Most of the participants used animals (cobweb, radiolaria, butterfly, coral, webfoot, fly, isopod, ray, albatross, synapse, fish, sea urchin, tortoise, bat) as bio-inspiration model; bio-inspiration from plants was quite limited.
- The majority of projects used performance features for bio-inspiration such as "flexibility, lightness and durability". Other selected features are "sparkling, softness, electricity generation, structure and wingspread".
- The preference of aspect of bio-inspiration model to reflect to design was equal. 5 of groups selected to reflect "technology" aspect (coral, webfoot, ray, synapse, tortoise); 5 of groups selected to reflect "material" aspect (cobweb, radiolaria, butterfly, fly fish) and

5 of groups selected to reflect “form” aspect (isopod, albatross, mushroom, sea urchin, bat) of the bio-inspiration model to their design.

At the end of the workshop, design guide notes, field notes and interview notes were analysed to reveal participants’ preferences between solution- and problem-driven approaches in the biomimetic design process and between form- and principle-oriented abstraction in their designs as well as potential differences in the biomimetic design process between students in the earlier stages of design education (first grade and second grade students) and students with more experience in design education (third grade and fourth grade students). Design guide notes of the students were used to gather data on what grade the students were in, their preference between solution-driven and problem-driven design approaches similarly to biomimetic design approach, and how they implemented design steps like principle- and form-oriented abstraction. The results have been analysed and evaluated:

Evaluation of the preference between solution-driven or problem-driven approaches in biomimetic design among students:
Data based on the design guide notes of the participants show that the solution-driven approach was preferred to the problem-driven approach in 12 of 15 designs. In the interviews, participants expressed that the most important reason they preferred the solution-driven approach in the workshop was that it was easier to find a design problem based on an existing biological solution”. Accordingly, this case has confirmed the hypothesis presented by Helfman & Reich (2016): “*It might be easier to find analogical design problems to a given biological solution than finding an analogical biological model to a given problem among the millions of potential biological sources.*” Another reason for this orientation may be that the design problem has already been determined as a pavilion even if the function has not been specified. Three designs that employed the problem-driven approach were developed by both students in the early stages of design education (first grade and second grade) and students with design experience (third grade, fourth grade). In this sense, no significant difference has been observed in design approach among students’ grades.

Evaluation of the preference between principle-oriented abstraction and form-oriented abstraction among students:
Data based on the design guide notes of the participants and field notes has shown that “principle-oriented abstraction of a natural organism/process/ecosystem” was preferred in 10 of 15 designs. None of the students with design experience preferred “form-oriented abstraction of a natural organism/process/ecosystem”; all five of the designs that employed form-oriented abstraction were developed by students in earlier stages of design education. Therefore, this case has showed that students in the early stages of design education (first grade and second grade) tended towards “form-oriented abstraction of a natural organism/process/ecosystem” and students with design experience (third grade, fourth grade) tended towards “principle-oriented abstraction of a natural organism/process/ecosystem.” In the interviews, students in the early stages of design education expressed the reason why abstraction could not go beyond form-oriented in the search of a biomimetic solution was that “they had difficulty in finding a starting point when they started designing and gravitated towards form”. According to Felek & Gül (2019)’s

research, implementation of various strategies to boost creativity of the students in the early stages of design education during the process of interior design is seen as beneficial. For this reason, in future workshops, a method of creativity can be integrated into the design guide in order to facilitate the principle abstraction phase for students with little experience in design. However, these students also expressed that "they preferred form oriented abstraction because they could not fully understand biological processes (survival techniques, response to climate, adaptation to environment) of biomimetic models" and stated "as they could not clearly understand the rationale behind the biological process, it was easy to use form as a design tool rather than the principle". According to Farel & Yannou (2013), the designers that practice biomimetic design suffer from a lack of biological knowledge, so through the participation of a biologist in the team, the team's knowledge base will expand and this will lead the team to innovative design solutions. For this reason, in future studies, a workshop open to design students and also to students from other disciplines such as biology may be organized in order to expand group's biological knowledge.

Conclusion

Biomimetic design has been the foundation of a many great innovative designs throughout history. However, there is still a lot to understand about design practices from the biomimetic approach, the underlying cognitive mechanisms, and methods preferred to implement and teach the approach. As one of the disciplines that use biomimicry for inspiration, interior architecture generally utilizes biology as a library of forms; however, this alone is not biomimetic; the design itself must involve biology. This workshop was useful to introduce students to the possibilities and significance of biomimetic design, to use biological principles as an inspiration tool in spatial design. The study, firstly examined the biomimetic design approach and application methods, and then analysed a workshop that aimed at integrating these methods into spatial design. In the final section, structure, learning expectations, outline and outcomes of the workshop were discussed. It was observed during the workshop that most of the students preferred the solution-driven approach to the problem-driven approach, because students mostly believed it to be easier to find an analogical design problem for a specific biological solution, therefore, gravitated towards the solution-driven approach. Another reason for this orientation may be that the design problem has already been determined as a pavilion even if the function has not been specified. The second research question was about the preferences of students between principle- and form-oriented abstractions. The goal of biomimetic design approach is not only being inspired by forms but also understanding and adapting the functions, characteristics and processes that constitute the form. It has been observed that first and second grade students have difficulty in the adaptation/abstraction process as they imitate a natural organism/process/ecosystem. These students have pointed out that it was difficult to find a starting point in design process and they found solutions by thinking form-oriented. They also stated that they were directed to form oriented abstraction because of their limited knowledge and understanding of biological references. All third and fourth grade students developed designs by using functions, characteristics or processes rather than the form of the natural organism/process they mimicked.

The limitation of this research is that the biomimetic approach has only been tested through one workshop. This is just a first step for discussing the experience of implementing the biomimetic approach to interior architectural design in an informal education environment. The approach needs to be tested further where the research is an experimental or testable protocol setup and with sufficient data collection to permit a comparative study (a statistically significant sample size). Besides, based on this biomimetic design experience, it is proposed for future studies to introduce a more flexible design problem to facilitate attempts to use the solution-driven approach as much as the problem-driven approach, and add to the biomimetic design model a guiding step that involves a method of creativity that facilitate abstraction and directs students who are in the earlier stages of design education to be oriented in principle rather than form. Another suggestion to facilitate this process is to organize a multidisciplinary workshop open to design students and also to students from other disciplines such as biology. In this way, biological knowledge transfer may become more accurate and efficient; so that design students could more easily understand, synthesize and use the principles of biological references as design data.

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Framing craft and performance in hybrid puppetry workshops

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Abstract
Prototyping Puppets combines craft and performance in a puppet making STEM workshop for informal learning. We report on its final evaluation in two events (n=10 and n=13) to show how the design addressed black boxing of technology through a craft-centric approach and successfully engaged different student populations through an educational framing that included performance practice. The informal learning workshops are aimed at 5th grade level students. First, the problem space is laid out and the approach of the project introduced. Second, the design realization is briefly covered. Third, the final evaluation of the design in two workshop conditions is presented using qualitative as well as quantitative data. Students showed self-perceived increases particularly in their attitudes toward technology. These results are discussed before we report on the adaptation of the workshop for different conditions to illustrate the flexibility of the basic set up.

Keywords
craft, informal STEM learning, puppetry, performance, making, adaptation

Designing prototyping puppets
Prototyping Puppets is an exploratory informal learning research project conducted in Georgia, US. It targets students near the end of elementary school to teach them basic skills in circuit building and electronics. The project targets informal STEM learning but to focus on its key audience, it follows Next Generation Science Standards Engineering Design guidelines (States, 2013) and aligns with Georgia's Academic Standards (Cox, 2004) of 5th grade education. Key technical elements include topics of conductivity, polarity, and simple electronic components such as switches and LEDs.

The project developed a workshop curriculum that combines methods from craft and performance in a puppet-making and -playing exercise. Students construct basic rod puppets consisting of a double-sided paper-puppet build around a craft-stick to hold and manipulate the puppet. During the process, students learn fundamental principles of circuitry and combine physical making with prototyping electronics as each puppet also includes a simple circuit that students create and operate. The workshop uses student-driven narratives and collaborative performances to motivate students of varying interests. It addresses two key challenges in

STEM education: 1) to attract and engage diverse student audiences with varying interest in STEM-topics and 2) to counter black boxing of technology. The following will outline the design criteria, development, and evaluation of the project, which saw assessment throughout its different stages. The essay will focus on the final evaluation through two afterschool workshops (n=10 and n=13), which included quantitative and qualitative feedback from instructors and students. The argument closes with a broader impact outlook, illustrating how the project was adapted by external instructors and fit into new contexts.

Problem and Motivation

Prototyping Puppets leans on craft practices and simple materials to push basic functionalities of circuit building to the forefront. A second foundation of the project was its reliance on the integration of performance practice to attract new students and keep them engaged. In combination, craft and performance were not used to necessarily lower any entry threshold but to spread engagement wider, reach different student populations, and inspire by tackling underlying circuitry logic, not hiding them.

A prevailing call to educational STEM kits is to support context for their teaching technologies and approaches (Peppler, 2013). It is "fundamentally important for any student to be able to frame any STEM topic in a personal, thoughtful and meaningful context so as to allow for open inquiry, discourse, and evidence-based reasoning" (Zeidler, 2016). But as optimized kits focus on the support of a particular technology, the origin of the operation and the cultural role of the mechanisms the students build can become secondary. STEM science labs might ask students to concoct particular solutions that will grow crystals or assemble blocks to build a specialized robot but the nature of the crystal or the robot themselves remain unexplored. This can detach students from the activity at hand. Such detachment fails to overcome a "not for me" perception especially among female students (Archer et al., 2013). Even successful STEM projects, like the iCODE project, report difficulties to attract female audiences (Martin et al., 2011) and can struggle to provide a solid cultural and engaging context – an "interconnected whole" (Katehi, Pearson, & Feder, 2009) – to attract and engage new students. A second challenge of standardized kits is that most of them attempt to simplify access to complex challenges and to achieve this they hide more complicated components. Access might be enabled but the underlying logic of a particular technology might be hidden from sight in the process. For example, LEGO Robotics offers a rich tool kit to teach STEM skills but requires careful scaffolding by teachers (Castledine & Chalmers, 2011). If this scaffolding builds onto the tool kit without critically questioning the provided functionality, the integrated functions are used as a given. This can lead to black boxing. Black boxing is caused by containing complex technical problems into prepared sub components. A designated block might specialize on a task such as receiving some input and applying it to a separate block which might specialize in applying motion via motors. But neither block would explain the underlying technologies used to achieve these effects, nor can they be re-shaped to fit personalized aesthetics (Mellis, Jacoby, Buechley, Perner-Wilson, & Qi, 2013). Such optimization can lower entry thresholds and inspire students to embrace existing tools but by definition it hides and mystifies underlying technology. Craft and DIY based approaches have been deployed as own learning approaches (Pirttimaa, Husu, & Metsärinne, 2017) and own approaches toward possible tool kits are emerging. This includes the 'kit-of-no-parts' "where electronics are crafted from raw materials" (Perner-Wilson, Buechley, & Satomi, 2011) or material-based approaches, like using conductive playdough, to reach new student populations (Peppler, Wohlwend, Thompson, Tan, & Thomas, 2019).

Craft and material culture remain useful tools in teaching STEM (Ólafsson & Thorsteinsson, 2009) and new materials and technologies have become accessible that allow for a combination of traditional craft approaches with electronics and digital media. This nexus of traditional creative practice and new technology has led to a range of successful projects. Buechley et al. even spoke of the dawn of a "a new educational subculture" (Buechley, Eisenberg, & Elumeze, 2007). It has fostered a range of formal and informal STEM learning projects in soft circuitry (Peppler & Glosson, 2013) or paper (Mellis et al., 2013), as well as educational game design approaches based on craft (Horn et al., 2016), and reaching into "maker" cultures, where a focus on craft has been effective to engage female students (Sheffield, Koul, Blackley, & Maynard, 2017).

The *Prototyping Puppets* project continues this trajectory and builds on existing work (Peppler, Tekinbas, Gresalfi, & Santo, 2014). It combines basic prototyping materials with craft and performance – not by "utilizing" one over the other but through the integration of both domains in a single activity. Its contribution is the development of a workshop design that balances crafting and performing as engaging activities to support STEM teaching in an informal workshop design centered on puppetry. Puppetry as a creative practice has a long tradition in education (Kroflin, 2012; Krögera & Nupponen, 2019), which includes its use for STEM education (Walt & Potgieter, 2018). Various practical guidelines to use puppetry in the classroom exist (e.g. (Peppler et al., 2014; Smegen, 2017). Here, we report on the iterative design and testing of our concepts up to the concluding evaluation workshops conducted by educators in an afterschool setting.

Targeting Learning Objectives through Iterative Design

Inspirations for the project's craft components were taken from the work of Perner-Wilson on constructing basic circuits out of the most fundamental crafting materials (Perner-Wilson et al., 2011). This work uses crafting as an educational and engaging process itself, combines it with materials such as conductive thread or ink, and often foregrounds the function of components through this assembly. Participants might crochet a potentiometer or stitch a switch. This combination of hands on transparent technology making counters any hiding or for blackboxing of functionality.

On the performance side, the make-your-own-puppet workshops held at the Center for Puppetry Art in Atlanta (CPA) served as a key reference. Since its opening in 1978 the CPA is a leading center for puppetry art, conservation, and education in the United States. In its workshops, visitors use everyday materials such as paper, rubber bands, and popsicle sticks to build simple puppets that relate to the puppetry show currently running at the Center. They reach wide audiences and connect the making of a puppet to professional puppet shows as well as individual artistic exploration. The core design of *Prototyping Puppets* centers around a combination of these approaches in performance and craft practice. It required an iterative design approach to optimize and simplify the initial concepts.

The final version of *Prototyping Puppets* took the shape of a 3 hour workshop activity. The underlying learning approach is based on constructionism (Papert & Harel, 1991) but combines it with storytelling and performance activities. During these workshops, students build basic hand puppets that include simple circuits. They learn key concepts of electricity such as polarity and conductivity and cover translation of computational thinking into collaboration with peers and design thinking. The students use their puppets to act out a story they developed earlier in the workshop and test their technology in the performance. The embodied learning stretches from a crafted making to the collaborative performance. Here, we will focus on the final workshop instances and their evaluation in two two-tier workshops that first taught educators our approach and secondly observed teachers and their students as those educators taught our hybrid puppetry workshops to their students (n=10; n=13).

Puppet Design

In collaboration with the CPA, we initially developed a range of different puppet designs. Each of these designs used hybrid materials such as conductive thread, tape, or basic actuators to provide a crafting exercise in building a puppet and combine the mechanical construction with basic prototyping and circuitry. Figure 1 shows four sample design, using from left to right soft circuits and conductive thread in a hand puppet; a dual-puppet design where one component holds the battery and another uses a clothes pin to close a circuit; a string puppet using conductive thread; and a rod puppet close to our final sample puppet. The authors tested these designs in two workshops with educators as well as puppet experts (n=10; n=6) for improvements in materials and procedures.

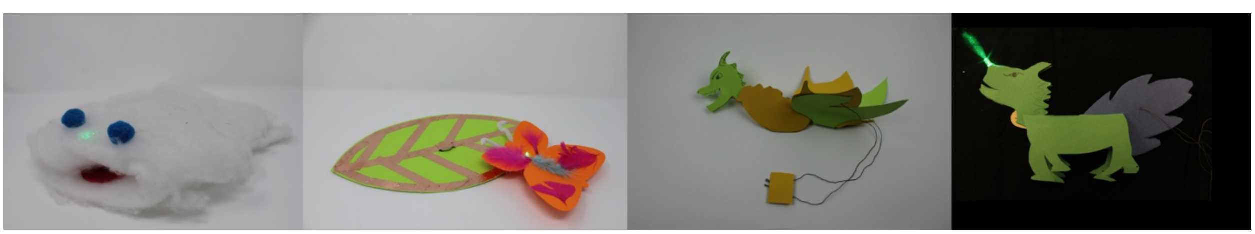

Figure 1. Samples of initial puppet designs tested with puppeteers and educators.

The designs and their documentation were optimized and tested in two additional workshops with students (n=8; n=9) to assess feasibility and inform further iteration. The puppet designs, documentation, and especially the educational framing were optimized once more. Results of these design-focused workshops have been reported elsewhere (Nitsche & Eng, 2018).

The final design of our base-puppet is realized in a double-sided rod puppet. Its body builds around a central rod which carries a simple circuit using conductive copper tape, a 3V lithium Ion battery, a LED, and a switch. This central spine is formed by a wooden rod that separates positive and negative sides of the circuit and also serves for the handling for the puppet. To allow expansion of the basic model, the full online documentation also covers other variations, including versions using Piezo speakers, small motors, or hook ups into other systems such as LEGO Mindstorms.

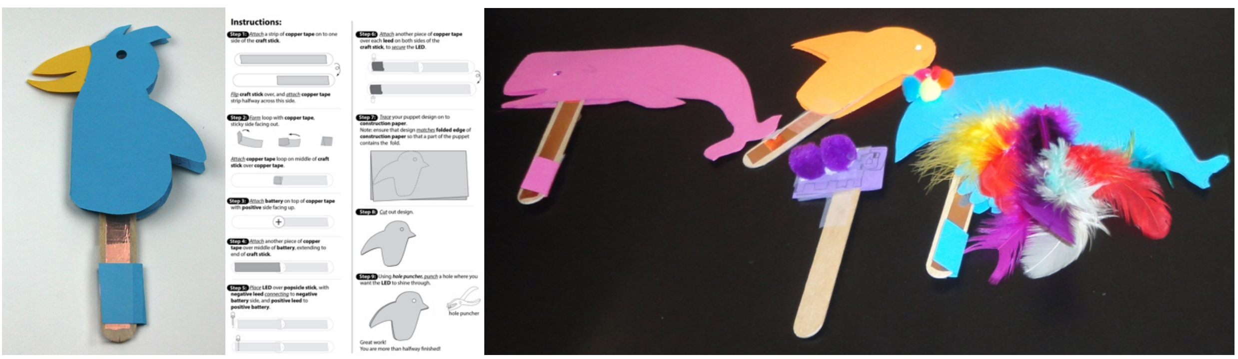

Figure 2. Default design (left); excerpt of instruction package (middle); samples of student-build customized puppets (right).

The design combines simple crafts and puppet making not unlike related projects (Peppler et al., 2014) but its focus, here, is less on the puppet design as the solution. The basic puppet serves as a blue print for further development, customization, and ultimately performance. While the material craft-based design foregrounds transparent technology (e.g. separating polarity through the rod control stick), the customization emphasizes personal context-building, collaboration, and ownership through expression and remained part of the educational framing to increase student engagement.

Educational Framing

Building the basic puppet prototype is the first part of a four-step teacher-led workshop that frames the *Prototyping Puppets* as an informal learning experience. The work-shop stages are: 1) Learn the underlying technology, 2) Create a shared story, 3) Create your customized puppets, 4) Rehearse and Perform together. Each workshop lasts about 3 hours in total. Through this structure, students encounter the technology, contextualize it with their own story, and build hybrid objects that encompass both circuitry as well as story to bring both to life in a concluding puppetry show, which also serves as a technical dissemination.

During this progression, ownership gradually shifts toward the students as they develop their own puppet concepts. Students encounter the initial puppet design, components, and circuitry as taught by an educator. But as they collaboratively develop a storyline, characters for that story, as well as props and scenery, they increasingly control the elements of the workshop until they perform as a team the concluding puppet show with the educators largely as audience to the now student-led activity. Emerging ownership in co-creative processes like these has been emphasized as individual as well as social dynamic processes that support informal learning (O'Neill, 2005).

Table 1. Workshop activities and individual stage durations

Stage	**Activity**	**Length**
	Introduction	10 minutes
Learn Technology	students familiarize themselves with the materials and designs at hand by building a default hybrid puppet	20 minutes
Create a shared story	students outline a shared story they want to perform	45 minutes
Create customized puppets	students build their customized puppets, props, and stages for their story	60 minutes
Rehearse and Perform	students rehearse their performance together and adjust their shared storyline into a final show	30 minutes
	Wrap up and reflection	15 minutes

Just as the puppet designs followed an iterative design approach, the documenting materials (video and print) were iteratively developed. This documentation included a pdf file that educators can download and print out for use with their students, but also can use as an online file with embedded links to the various steps of puppet assembly documented in a YouTube video. Instructional approaches consolidated as the supporting materials covered also story-building and put more emphasis on the rehearsal stage, which had been neglected in the first versions.

Design and Implementation of the Study

The final studies evaluated the resulting workshop designs. Each study was performed in two parts. The first consisted of a preparation session with the educators. Researchers met with them for a 45 minute session and taught them the technical steps of how to create the rod puppets, introduced the documentation, and left them with kits to explore the activity themselves. These preparatory workshops could include additional visiting teachers who were interested in the technology, but only data from actually participating educators in the whole study was collected. We tested the designs in two programs, one taught by one teacher, the other by two co-teachers. At this stage, mainly qualitative feedback was collected to test for possible shortcomings in our documentation and our educational approach.

At least one week had to pass before the second stage of the study followed. In this stage, the teachers administrated the full puppet workshops to their students. The break allowed for special preparation of material and/or modification of our approaches by the educators. Each workshop was a select group of students, based on teacher choice, and student availability. Because the student population of the first school was much larger than of the second, the recruitment there reached further to guarantee a diverse group of students. Both final student workshops happened outside of normal class operating schedules and were each 3.5 hours long. Workshops were held in school environments, a classroom and a STEM room, as informal after school club like activities. Neither student group was recruited from any single class and the events were outside usual teaching conditions. For example, they did not include any grading or teacher assessment.

The first study's (WS 1) teacher was an experienced (11 years of practice) teacher with extensive expertise in crafting and making practices, including electronics. The second workshop (WS 2) was held by two teachers. One with 10 years of practice, working as Art teacher at the school. The other, a STEM teacher with 18 years of experience in education.

Workshop 1 (WS 1) was conducted as an extra-curricular STEM workshop at a charter school Workshop 2 (WS 2) was conducted as a STEAM exercise for an after-school robotics club at an Elementary school. Neither workshop was part of any existing curriculum, neither included grading or other formal assessment from the instructor, neither used a single homeroom population but instead mixed students from either clubs or different classes. Both workshops managed to conduct the full exercise in the allotted time frame. Construction included props, such as simple cages, backdrops, and puppets. The stories were developed by students collaboratively in both events and resembled action-driven fantastical adventures.

WS 1's story was set in the future in an animal wizardry school where teachers are getting abducted by arriving aliens and need to be rescued by their students. The performance included scene changes and integrated the LEDs, for example, in the alien designs.

WS 2's story centred around a zoo, where a fire broke out and all animals escaped and broke into a fight. The worst of them ends up in a police car, while the rest extinguishes the fire and eventually return to their cages. They integrated the use of LEDs in their story at various points: as fire indicators, during the fights, as well as for the police car lights.

Data collection and results - teacher involvement

Data collected from teachers consisted of a pre- and post-questionnaire, field notes, and interviews after the workshop that followed core questions. Interviews were transcribed and analysed either by an external evaluator or three researchers through individual analysis and shared discussion. The main data presented here regards the qualitative feedback collected in the final interview.

The teacher for the first workshop (TWS1) had conducted the original puppet construction before as part of a STEAM day activity at school, led by the teacher. To prepare for the workshop, the teacher had prepared versions of the original assembly instructions in clear sleeves and showed the project introductory video to the students beforehand. The teacher valued the documentation and particularly the assembly construction: "I think just having me show it, and then having the visual to go back was very good for some of them. They're still working on refining their listening skills and their attention." (TWS1). The educator also noted that students were able to refer back to the instructions during the making process of their individual puppets, "so that when they went to make it on their own, they could come back and reference it." (TWS1)

One single table was set up for the students to work on during the workshop. The teacher had referenced the provided assembly documentation but did not use the storyboards/ narrative documentation during the story generation. Instead, students assembled the story on a whiteboard under rubrics that resembled the categories provided in the documentation. This emphasized the shared story building and made the story construction itself more performative as well as accessible.

Once the shared story backbone was constructed, the students spread out to develop their puppets, props, and backgrounds. Some worked in the hall outside the main room. The final performance was conducted in a different room: a hallway where the school had stored a designated puppet theater stage.

The second workshop saw two teachers conducting the workshop together, one the designated STEM teacher of the school (TWS2), the other the art teacher (TWS3). While the documentation was deemed good, they did not use the documentation materials in the workshop. Both stated that they were "very visual" in their learning and TWS2 noted that "for me the most helpful was the visual, watching" the making processes during the preparatory teacher workshop. Instead, one (TWS2) had prepared a separate poster that explained key concepts of the workshop. After the initial construction session, students were allowed to lead most parts of the rest of the workshop (e.g. they set up a vote on the story to choose by themselves). This showed a hands-off teaching approach that encouraged self-organization among the students.

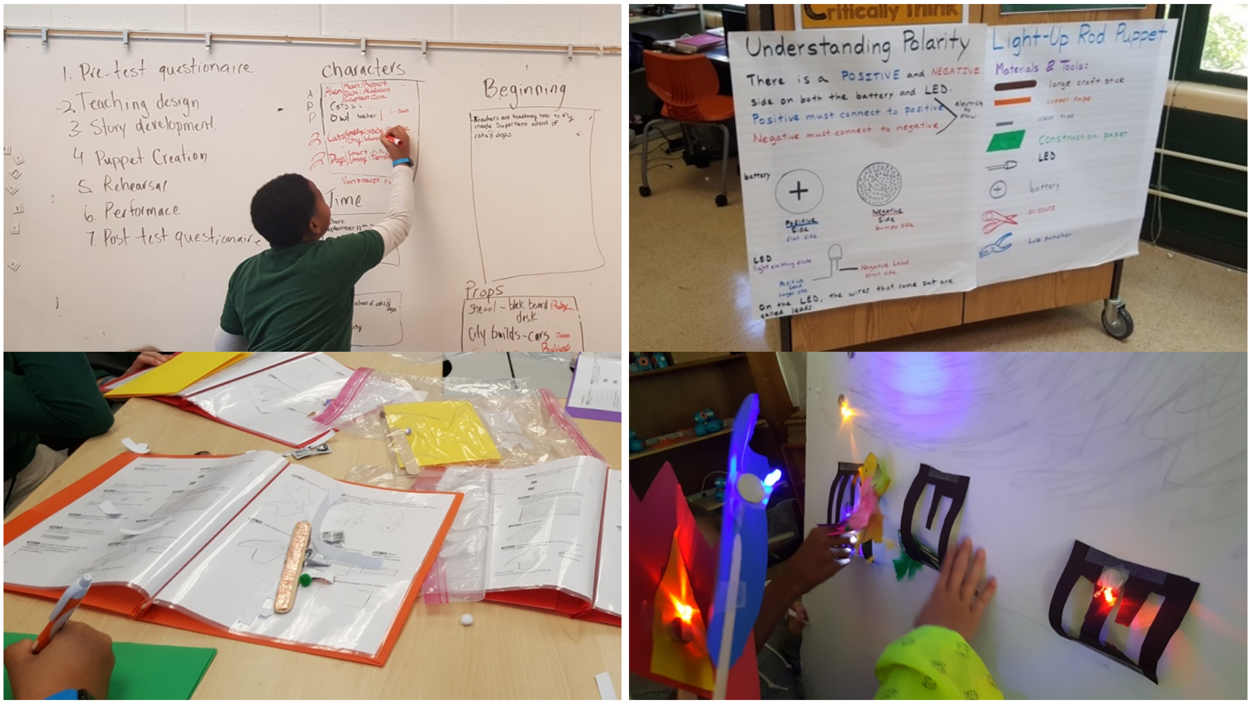

Figure 3 WS 1 (left): replacing the storyboard in the documentation with the whiteboard and re-usable instruction sheets; WS 2 (right): teacher-created poster and rehearsal of puppet scene.

In the teacher feedback for workshop 1 (TWS1) the room set up was not seen as optimal, having a too small table. The teacher also argued for a smaller group size of 5-7 students even though the group had successfully finished the workshop. The best form of teacher preparation was mentioned to be repeated assembly of puppets before the actual workshop. To that matter, TWS1 lauded the documentation and the video of the assembly. The workshop materials were seen as effective with the possible addition of pre-cut models for the blueprint first construction in stage 1) of the workshop and some more crafting and customization materials for the decorations. Notably, while some additions and simplifications to the craft-side were mentioned, none were given for the electronics side. The teacher did not note any additional changes to the circuit building instructions and materials.

TWS1 further connected the workshop to both Science and ELA standards but to fit it into a formal education plan, she called for a more gradeable rubric. A rubric would also clarify expectations among students and clarify focus point for the teacher to support further.

> "Before they even build it, I might read through the steps and let them see, 'Here's what I'm looking for,' so they'll make sure that they're doing it a little bit more diligently. Like if they know I'm going to grade their puppet, they will not want to make silly mistakes and things like that." (TWS1)

In its current form, the workshop was conducted in an informal setting where these rubrics did not yet apply.

A second opportunity for improvement was increasing opportunities for peer-tutoring by students. TWS1 mentioned opportunities for quick learning students to teach others during the exercise. The integration of electronics was not a problem but some students embraced them faster than others, based on their prior knowledge in the field. These students could support the workshop:

> "I think any of these kids in this group would love to go and reteach it. If you saw, I think there were 2 boys who were at my STEAM. They were moving ahead of me." (TWS1)

Thirdly, the teacher recommended a more guided rehearsal phase. TWS1 recommended that the students record a rehearsal of the performance and then review the recording to make improvements. "[T]he performance seemed a little sloppy and not as refined as I probably would have liked it. But I think that takes time. I would probably prefer to do this over a couple of days." (TWS1) For TWS1, rehearsal and performance took on a stronger role: "I would probably have preferred it to have a little bit more of a script and have them write out more of what they're saying." (TWS1) In contrast, the current set up "uses" these stages more as a technical-artistic validation but not as a graded activity itself.

The second workshop had two educators co-teaching (TWS2 and TWS3). Here, the construction of preparatory material (see table 1, upper right) was itself a learning process for TWS2:

> "I put it on the chart paper, that also helped me to be able to explain to them and also understand myself because I was only doing it the second time, because I think as a teacher the more we do it we learn more and more how to make it better, and we also, to teach better, like the next time we do it I bet we'll come up with more ideas." (TWS2)

Both teachers of the second workshop agreed that for preparation "the main thing is practicing it yourself" (TWS3) as well as making the motivation and target clear. Both noted that the visuals were the most import part of the documentation but did barely use the actual documents in their own preparation. The video was watched by one, but the other had problems with a blocking of the (YouTube) site. In addition to the existing materials, they called for more documentation on possible errors and about the "things that can go wrong" (TWS3) to allow students to make mistakes (TWS2 + 3). During the workshop itself, the teachers added halfway through the workshop a big clock that gave students a better idea of what to deliver when.

Both teachers focused on creative choice and exploration in their feedback: "So I would do that mini lesson where I would teach them how to create the circuit and how to make it work- and its up to them how they utilize it in their work." (TWS3) The circuit building was not seen as problematic and the materials and instructions were seen as sufficient, but the purpose of building circuits for one expressive object (puppets) only was seen as limited. The circuit building was suggested as a more independent part,

> "then they can use that stuff to build other things and within their own artwork and in that circuitry and it could be other things besides LED lights, anything that can have power and it could be part of their artwork because there's plenty of artwork out there that uses circuitry and power and balance." (TWS3)

But they realized that this would require more time commitment and a longer structure of the exercise. To implement this, they suggested to spread the workshop across different subjects and over multiple days of engagement.

TWS2 and TWS3 both mentioned the impact of time constrains particularly for the teacher. While the time frame was seen as a challenge, the workshop was considered a success, as "they [=students] were able to get their own ideas in" (TWS2) and "[t]hey stepped up" (TWS3). Peer tutoring was noted as an effective way of learning (TWS3) as well as a good way to provide coherence over time as student generations grow out of clubs and projects and graduate to new schools (TWS2).

Across both workshops, the existing documentation, materials, and overall structure were seen as sufficient. Wider ranges for the craft-based side were noted more than changes to the circuitry teaching but suggested improvements concerned largely time management and how to expand the condensed version of the single workshop format across longer periods of teaching. In addition to strengthening cross-curricular integration, peer-tutoring, and an opening up of the designs for other formats were suggested.

Data collection and results - student involvement

Quantitative student feedback was collected in questionnaires before and after the workshop. Questionnaires used multiple Likert scales to probe for changes in perceived attitudes towards electronics and craft/ art. They also asked for students' feedback on the workshops and their designs as such to assess efficiency and engagement. Each workshop started with an initial demographic questionnaire and closed with a comparative assessment questionnaire and a group discussion. All instruments were facilitated by the researchers.

The first questionnaire covered basic demographics (age, race, gender) but also asked for pre-existent knowledge in related STEM toolkits (such as Mindstorms, MakeyMakey).

The concluding assessment questionnaire was designed to identify effects of the workshop on students' changing attitudes toward electronics and art/craft. The assessment questionnaires included a self-assessment of students' attitudes towards these two components. This was assessed through a 10 point questionnaire designed to cover 7 main qualities through cross-referencing (Confidence, Enjoyment, Importance, Motivation to succeed, Identity, Intent to persist, Creativity). Questions directly asked for students' self-assessment of that quality (e.g. "I am confident when it comes to electronic/ arts and craft"). We tested the qualities of Enjoyment, Intent to persist, and Creativity with two questions each to make these qualities more accessible for students (e.g. Enjoyment was recorded in asking whether working with electronics/ arts and craft was "fun" as well as perceived as "comfortable"). No outliers between these two questions were recorded in either of these three qualities.

The same ten points were asked for perceived changes in attitudes to craft and to electronics and assessed as before/after Likert scales.

In addition, the assessment questionnaires included questions that explored the workshop itself and its perception. It asked on a 5 point scale whether the workshop was perceived as difficult/ easy, engaging/ boring, not useful/ useful, creative/ not creative, not satisfying/ satisfying. This questionnaire also asked whether students would recommend, repeat, and overall enjoyed the workshop itself as an exercise. Regarding the students rating of the workshop as such, Figure 4 shows the weighing for the dominant of each pair.

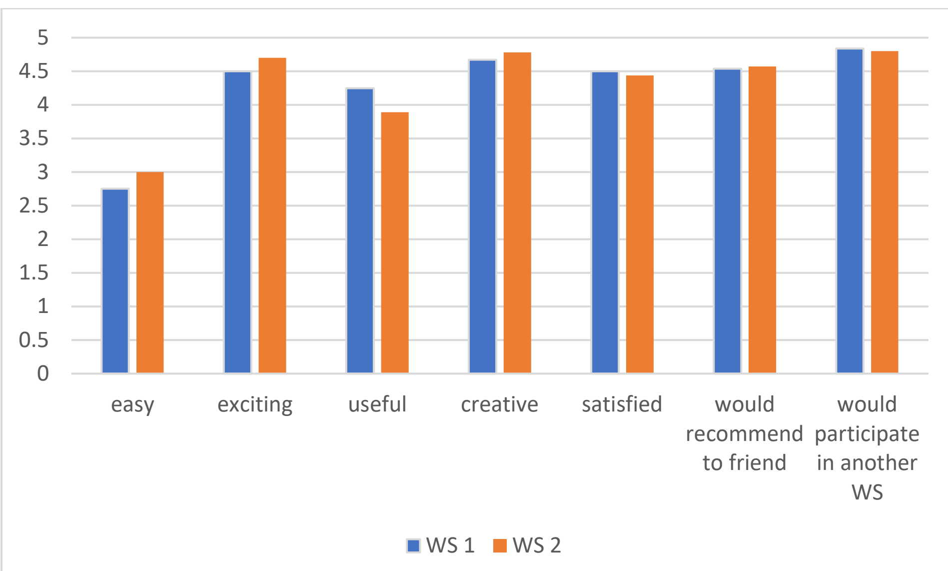

Figure 4. Students rating the workshop activities (0=negative 5=positive).

Students of both workshops rated the activities overall high (see Figure 4) with the highest ratings in agreement to participate in another workshop like this (WS 1=4.84; WS 2=4.8 with 5 being the highest possible rating). The single outlier was the rating for perceived challenge, where students assessed that the workshop was perceived as either "easy" or "challenging." Results here were balanced (WS 1=2.75; WS 2=3).

Students' perception of changes in attitude toward technology were recorded in Likert scales. Both workshops reported improvements across all seven qualities. Students in both workshops reported an increase in their perceived knowledge in electronics (see Figure 5). WS 1 reported an increase from 3.85 before to 4.25 after the workshop (increase 0.67). WS 2 reported an increase from 3.30 to 3.90 (increase of 0.60).

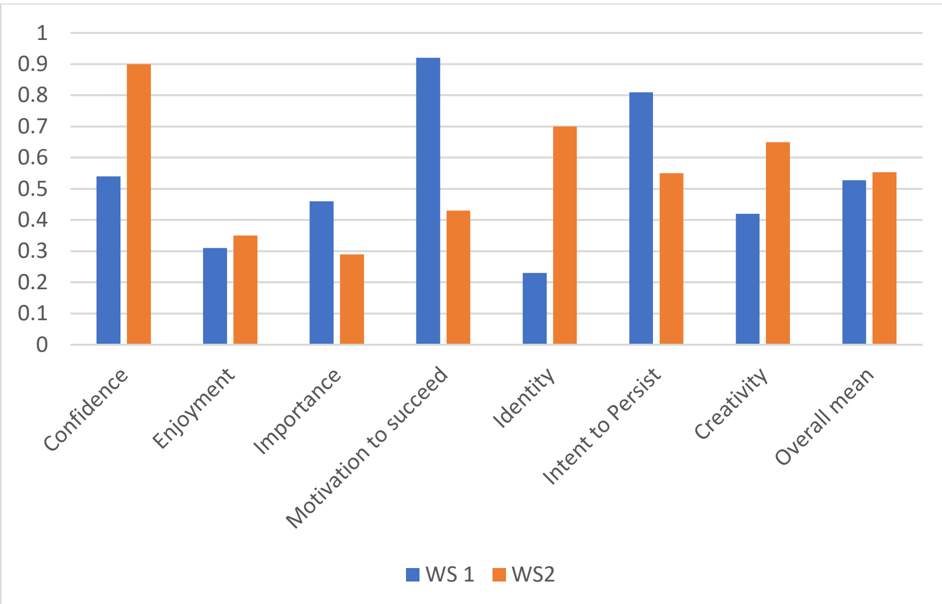

Figure 5. Changes in attitude regarding technology between WS 1 and WS 2.

The self-perceived changes in attitude regarding technology before and after the workshops vary but the overall improvements are comparable (mean WS 1=0.53; mean WS 2=0.55). Notable outliers are the increases in "motivation to succeed" (WS1=0.92; WS 2=0.43) and in the "confidence" increase (WS 1=0.54; WS 2=0.9 increases).

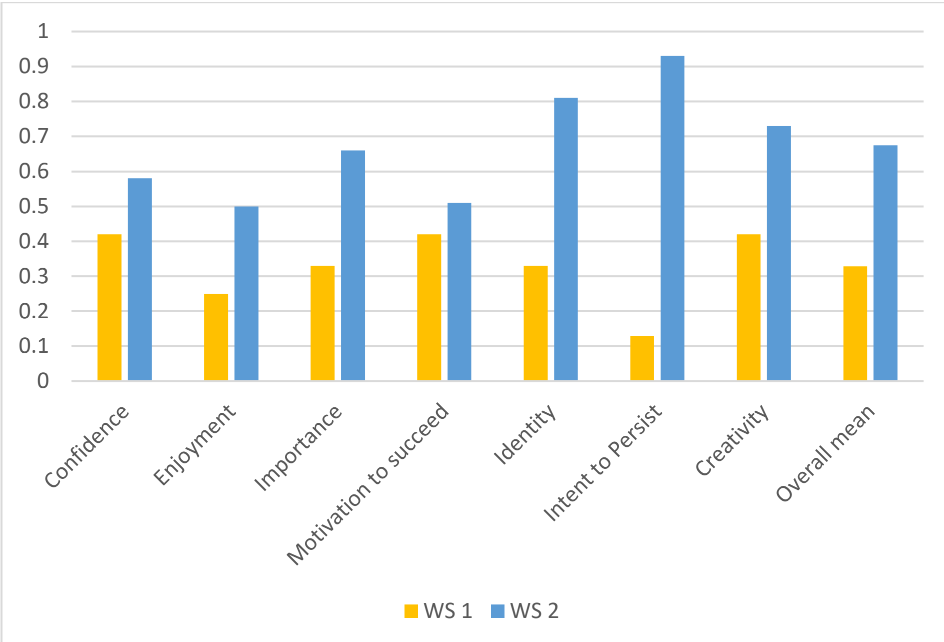

Figure 6. Changes in attitude regarding arts and craft between WS 1 and WS 2.

The self-perceived changes in attitude regarding arts and crafts differ more clearly between the two workshops (see Figure 6). All showed increases but the perceived changes were higher in WS 2 (mean WS 1=0.33; mean WS 2=0.67) with especially clear differences in the improvement of attitudes regarding “importance” (WS 1=0.33; WS 2=0.66), “identity” (WS 1=0.33; WS 2=0.81), and “intent to persist” (WS 1=0.13; WS 2=0.93).

Qualitative feedback was collected in concluding group discussions and open feedback forms on the questionnaires. Students emphasized that they appreciated the workshops overall and especially the making part but equally noted the performance part in WS 1. Time management was seen as a challenge but unlike the teachers, the students enjoyed the freestyling performance more. As one student participant in WS 1 mentioned: it was the “coming together” that seemed to keep them engaged and “how we all helped make the show.” In the same session, one student lauded “The ending when we made up lines, and it was funny when we messed up a lot.” Failure was not seen as a threat, as another student noted: “The best aspect of this workshop is that no idea was wrong and everyone got along.” Likewise, students in WS 2 emphasized both, the “show experience” as well as the building sections that were perceived as fun activities. Students in WS 2 also noted collaboration and teamwork as positive aspects: “The best aspect was that we had to be creative and collaborate.” No problems with the electronics were mentioned, yet more possible materials for their customization were called for.

Discussion

Here we present only the final evaluation data but we recognize that the same distribution was found between earlier researcher-led workshops. Whether the workshop was given by an educator, who had to be taught to deliver the workshop, or by the researchers and designers of these exercises, caused no significant difference in the students' perception of the activities. This indicates a successful documentation and material transition from the researchers to the teachers. This is supported by the fact that in both cases, the educators succeeded in conducting the whole workshop in the designated time without any specific delay or complication.

The workshop activities were rated highly by students throughout (mean WS 1=4.13; WS 2=4.16) with only the value for perceived "challenge" in a medium range. This indicates that the workshop overall balanced difficulty levels for all students involved. It was neither too challenging nor boring in its activities. This supports successful engagement overall while they still appreciated the workshop format.

In terms of self-perceived attitude changes, student participants in WS 1 reported in their demographic questionnaires an overall slightly higher initial interest in "performance/ art" than participants in WS 2 (WS 1=4.31; WS 2=4) while the picture is reversed in the higher initial interest of participants in WS 2 in "electronics" (WS 1=4.38; WS 2=4.7). The student group in WS 2 was more coherent as they were all members of an afterschool robotics club, which focuses on technological competitions, such as LEGO robotics. Students participating in WS 1 were more diverse in their interests but overall identified closer with the arts and craft side.

We read this difference in initial interest as the main factor for the differences in the perceived attitude changes in "art and craft" between the groups. WS 2 shows higher increases in this category than WS 1. With an initially lower interest in arts and performance among the robotics club students in WS 2, the opportunity for increase was larger. The data indicate that the puppet performance and story development unlocked some of the artistic interests among the more technologically inclined students of WS 2. It still spoke to the students in WS 1 but did not trigger the same change in the perceived changes of their attitudes towards arts and craft because the initial interest was already given. In comparison, the workshop's overall effect on the students' perception of their attitudes to technology and was more balanced. All attitudes showed improvement in both domains and indicate a successful integration of technology with arts and craft activities. Course populations are bound to be diverse but the differences indicate overall improving attitudes across the board as well as higher impact where the initial ceiling was higher. This supports the core goal of this study: to attract and engage diverse student audiences with varying interest in STEM-topics. Differently motivated student groups remained engaged, showed increases that reflect learning potential, and all managed to succeed in the workshop activities throughout. Krögera and Nupponen identified five key benefits for the use of puppetry in education: generating communication, supporting a positive classroom climate, enhancing creativity, fostering co-operation/ integration into a group, and changing attitudes

(Krögera & Nupponen, 2019). Our workshops confirm their summary and more specifically, we read increases in communication, creativity, and co-operation as a way toward diverse engagement through effective group work.

Educators clearly considered the STEM workshop as a success, not only in terms of sheer results but also for the student engagement. As one noted,

> “its very empowering. As a student, it’s difficult cause not a lot of kids get that time to ideate and to take risks and to come up with and use their own ideas because it’s usually the teacher telling them what to do.” (TWS3)

The combination of crafting and artistic presentation with technical making and electronics did provide them such an opportunity and in both studies, the final performance – which was mainly seen as a form of artistic validation and engagement from the researchers – was noted as an independent teaching and learning opportunity. At the same time, they were looking for possible additional assessment methods. Although these workshops were conducted in informal learning conditions, the instructors saw them as a good fit for their more regular formal educational work.

In summary, the workshops achieved the targeted student engagement through the combination of craft and electronics in an art-based performance frame. The activities were seen as engaging by both educators and students and triggered self-perceived attitude improvements toward technology as well as arts and craft. Another indicator for the success in this regard are the signs for successful collaboration among the students, which was noted as a key quality by students themselves. While this supports our claim that the workshops engage different audiences through their combination of art and technology in performance, the claim to counter blackboxing is less easy to prove. Perceived student attitudes toward technology increase strongly in both workshops and across all categories. This indicates successful integration of basic circuit building techniques but for a full evaluation, it would be necessary to apply more formal tests to assess students’ changed understanding of e.g. polarity and conductivity.

The fact that every student managed to build an own operating hybrid puppet, no matter what their initial interests were, indicates the value of the chosen craft-based pathway to teach basic circuitry. Students built individual circuits during the workshops’ first phase where technology was taught without any focus on customization of the puppet objects. Notably, the instructors did build on these electronics learning objectives, for example one provided an own poster with key concepts laid out. Students also showed basic adaptation, for example students in WS 2 re-used their original circuits built in phase one of the workshop to create the lit backdrops for their stage (see fig. 3 bottom right). Based on these observations, we argue that the chosen approach to combine craft and electronics in a puppet-based performative setting does encourage some exploration of the underlying technology through re-use and that such reappropriation indicates successful understanding of the basic underlying principles. Students have to know which part of a circuit they need to re-use it when creating a prop out of a puppet built in phase one of the workshop. However, to fully evaluate a countering of the black boxing effect, additional test that would provide comparative data (e.g. between groups that learn using a craft-based approach and those that use another approach) would be needed.

Outlook

The *Prototyping Puppets* workshops were designed to be adaptable and simple to implement. This includes accessible and affordable components as well as easy-to-adjust designs and documentation. As the evaluation workshops proved, the approach did work with local students. However, one unexpected yet encouraging development was the adaptation of our material for other workshops and events. All documentation was made available online and the kits have been used in numerous informal educational settings without the researchers' participation (and often without their knowledge). In some cases, educators re-designed our original concepts and instructions to adjust puppets to their specific cultural and local conditions. They highlight the value of our designs for different circumstances as well as their adaptability. Our own adaptation includes adjustments of the designs to workshops for local STEM events as well as for workshops at leading international museums. More interesting, though, are adaptations from third parties. These include local afterschool groups as well as international and national scholars/ educators.

Figure 7. Design adaptations: workshop on African-American inventors (Paulette Richards) (far left: puppet; left: instructions) and in Medellin (Isabel Restrepo) (right: community classroom; far right: bi-lingual instructions).

To provide two examples: one is an adaptation for a workshop on African American inventors by Paulette Richards, another one a range of adaptations for underserved student populations in Medellin, Columbia by Isabel Restrepo. In both cases, our original designs needed adjustments. These included translation into Spanish, change of the puppet shape, and even some material adjustments. The main design features remained the same but the concept proved adaptable to very different conditions. Creating such individual, non-prescribed forms of expression through storytelling and performance was a driving design directive for the project next to engagement through performance and craft-based technology deployment.

The flexibility of these designs provides one direction for future work. This work would target further exploration of the value of our hybrid approach in STEM education, particularly in its value to test the value of a craft-based approach in countering black boxing of technology. Our work adds an own approach to related research (Mellis, Jacoby, Buechley, Perner-Wilson & Qi, 2013) but lacks comparative evaluation.

A second direction for future work is further exploration of the performance-driven part of the project. STEM education has embraced related strategies, such as narrative, but we see further need to include performance as an integral practice. While our project remained limited to a particular setting, the value of puppetry and performance has be noted as a way to facilitate teaching of difficult themes, providing a safety for students to speak "through their puppets" and allowing students as well as teachers to adapt a personal style (Beer, Petersen, & Brits, 2018). In our case, staging the final evaluation of the built technology as a performance by students proved to be a highly effective and engaging choice that did not detach technology from art but realized both practices in combination. Exploring this approach further poses a challenge and opportunity for future STEM scholarship.

Acknowledgments

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Multistable Technologies and Pedagogy for Resilience: A Postphenomenological Case Study of Learning by 3D printing

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Abstract
Accelerated technological innovation induces disruptions in society and education. It results in both threats to and opportunities for the way the society learns and works. This case study examined the phenomenon of learning in a disruptive environment. The chosen typical case of a disruptive learning environment was comprised of multistable technology and multiple cross-disciplinary, stakeholders. To reveal how inexpert stakeholders cope with technological barriers, the study examined design studio education as a research site. There, groups of design students used 3D printing to develop assistive technologies together with patients and therapists. The empirical data collected on site was analyzed through qualitative content analysis and postphenomenological concepts. The study showed how new multistable technologies impose relational, fluid models of learning on site by revealing mediations between technology and humans. This new perspective on learning in disruptive environments informs practical sustainable pedagogical practices and theoretical approach to learning for resilience by expending vocabulary concerning technological education. It also proposes altered priorities for formal education. Instead of solely focusing on the knowledge content or learners' development, formal education should also take into account learners relations with their social and technological environment.

Keywords
pivot, multistability, field of awareness, 3D printing, resilience, integrity

Introduction – disruptive workplaces
The emergence of new technologies will bring major changes in the work market, but also opportunities that are yet to be explored. This is reported by Organization for Economic Co-operation and Development (OECD) in "Education 2030" (OECD, 2018). The future workplace environment will be one characterized by the solution of evolving and ill-structured problems, a

cross-cultural workforce, unpreceded technological development, and threats to the environment and well-being. The abilities of future students are characterized in this way: "Students will need to apply their knowledge in unknown and evolving circumstances. For this, they will need a broad range of skills, including cognitive and meta-cognitive skills (e.g. critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g. empathy, self-efficacy and collaboration); and practical and physical skills (e.g. using new information and communication technology devices)." (OECD, 2018, p. 5)

There is a need to explore how formal higher education can provide conditions for preparing learners for this kind of workplace and the pedagogies that can support this kind of learning. Further, there is a need to explore the role of technologies in the learning process. The research question, therefore, is: How can human-technology mediation facilitate resilient learning? The purpose of this study was to define a conceptual framework of learning for resilience through technology.

Theoretical perspective – a brief introduction to postphenomenological concepts

The aim of the study was to address the issues of preparing learners for the future rapid changing technologically informed workplace. The study therefore strove to define learning for resilience in the context of technology usage. To study and define learning and knowing through technology we engaged in postphenomenological discourse and methodology.

In the postphenomenological view, human intention is mediated through technology. For example, humans do not see the hands on the clock; they see the time of the day automatically. This *mediation* that technologies afford is reciprocal (Verbeek, 2015). Namely, technologies transform human perceptions by amplifying or reducing certain aspects of the experience and translate human actions by inviting or inhibiting humans to do or not do certain things (Ihde, 1990). Postphenomenologists have introduced other key terminology which is beneficial for understanding learning and utilizing 3D printing. The phenomenon when humans see the world uninterruptedly mediated by technology is called *transparency* (Rosenberger & Verbeek, 2015, p. 17). *Multistability* is a fluctuation of configurations and mediations between humans and technology. For example, a bottle mediates pouring a liquid but also holding a flower (Rosenberger, 2009). Another important term, *pivot*, was coined by Whyte (2015) and refers to the respective different forms of multistability. Pivoting is the tendency of the configurations of machines and humans to be transformed and reach new stabilities. Mediation can also present in different forms. *Fusion,* for example, is seen as a human-technological configuration where the mediation is immediate, for instance, with bodily implants that enhance human functioning (Rosenberger & Verbeek, 2015). The other configurations demand different kinds of mediations. Rosenberger developed two other variables that, like the notion of *transparency*, could characterize a user's technologically-mediated field of awareness, what he called *field composition* and s*edimentation* (Rosenberger & Verbeek, 2015, pp. 23,24). Field composition allows for a human-altered field of awareness due to technology facilitation. A changed or altered field of composition happens as human intention becomes defined by technological mediation and the human is not able to include other incitements in its field of awareness. *Sedimentation* represents past experiences imbedded in one's mind, which actively contextualize present experience. Sedimentation refers to the force of habit associated with a given human-technology relationship; that is, a relationship that is highly sedimented is one that is immersed in over time-developed bodily-perceptual habits. Finally, there is a concept that describes human ability to envisage effects of the technology:

> "The actuality of a piece of technology relates to how it is being used at a given moment, but it also denotes its social function, its conventional use; how a piece of technology usually is used within a practice. A technology's potentiality, on the other hand, covers various forms of unconventional use" (Kiran, 2015, p. 133).

Innovation accelerates multistability

In his article about speed and multistability, Riis observed that "Multistability in the postphenomenological sense has an inherent tension between stability and multitude, which is increased by the speed and technological innovations." (2015, p. 169). Accordingly, multistability coupled with rapid innovations "breaks down our sense of stable entities and practices. That is, when we move into an experience of a continual series of changes" (Riis, 2015, p. 170). He concluded by linking to Idhe's concept (2012) that "the ability to see, vary, and decipher" pivoting aspects in multistability is the literacy of the future "which is very much in demand in order to avoid losing direction and prioritize properly" (Riis, 2015, p. 171). We agree with Riis and have noticed how the failure to cope with multistability appears in education. A recent study on the introduction of computers into classrooms shows how the learners struggled to sediment this technology into their practice (Mercier, Higgins, & Joyce-Gibbons, 2016). Multistability puts demands on higher education, making learning outcomes obsolete very quickly, and learners end up with a large amount of declarative knowledge but lack procedural functional knowledge (Livingstone, 2018). We argue therefore that the acceleration of multistability creates challenges for the educational system. We also argue that "the ability to see, vary, and decipher" pivoting aspects in multistability is the literacy that formal education has to address, and that a new perspective on technological pedagogy is necessary.

Method - case study

The study aimed to describe events, roles, and relationships in the learning site of a four-week course in assistive technologies through technological mediations. The research setting involved multiple stakeholders in international cooperation with Sao Paulo State University and Oslo Metropolitan University, and included a local rehabilitation center Sorri in Bauru, its staff, patients with various disabilities, and their caregivers. The experience reported here is part of an international collaboration between institutions from Brazil and Norway on research and development of assistive technologies (Sandnes et al., 2017).

The mixed student sample included 8 female and 7 male students, of which 3 and 12 were Norwegian and Brazilian nationals, respectively. Only four students had previous experience with digital modelling, and only two had a very basic understanding of 3D printing. None of the students had been previously introduced to inclusive design or assistive technologies. The students were split into three groups, and each group was purposely comprised of students of diverse national backgrounds. The communication among students was in English, which was not their mother tongue.

Case study research design

Postphenomenologists often employ micro-scale case studies because it allows them to investigate relationship between humans and technology, also how instances of technologies inform individuals' choices, actions, and experiences in the world (Rosenberger & Verbeek, 2015). The case study methodology was therefore chosen as a means to investigate the phenomenon of using 3D printers for learning in a real-life context, namely design studio, especially as the boundaries between technological mediation and resilient learning are not clearly defined (Yin, 2017). The study was conducted as a representative or common single case with three examples. The typical design studio education and future workplace setting as described by the OECD is comprised of a multistable technological environment, ill-structured novel problems, cross-disciplinary and cross-cultural groups, and multiple stakeholders. The case is further typical as students are using 3D printers for learning how to design assistive technologies which is researched in pedagogical practice (Buehler et al.). It has been shown that 3D printers can be used for various purposes, but through a single fabrication procedure making them highly multistable.

This case study is instrumental as it uses a case to gain insights into a phenomenon of learning through technology. In this kind of case studies, the cases are not samples, rather the case is used to shed light on certain theoretical ideas and introduce new theoretical concepts (Yin, 2017, p. 38). The case therefore is intertwining technological multistabilities and learners' resilience. This is explained through three examples, each with two embedded units of analysis. The two embedded units of analysis, are chosen because they describe human resilience in postphenomenological terms. These units of analysis were set to reveal mediation between technology and humans so as to determine how the technology shapes human activities. The first unit of analysis explored how users encounter challenges with technology by tracking multistabilities and opaqueness. The second identified how they cope with it by tracking pivots, sedimentations, transparency, and potentialities. The human ability to mediate technology, manage and comprehend it, and find new practices worthy of engagement characterizes the ability to achieve sense of coherence (Antonovsky, 1987). The perceived sense is that a technological environment, even though multistable, is structured, predictable, and explicable, the resources are usable, and the challenges are worthy of investment and engagement represents participants' resilience. We collected data through participant observation, technological artefacts, sound recordings from the student meetings and tutoring, and student reports and reflection notes. These methods were used because it was necessary to study the process of mediation, but also the learners' reflections on their coping with technology and the task. We tracked the units of analysis through content and artefact analysis (Bengtsson, 2016). To examine the findings, the study relied on the postphenomenological concepts (Yin, 2017).

Researcher role

In this research, participatory observation relied on two researchers who had various roles in teaching. The lead researcher was a guest lecturer, and the course manager took part in the research as a coauthor. From the perspective of a student, teachers are not their peers, which puts them in the position of outsiders (Herrmann, 1989). Further, it also puts them in a position of power over the students (McNay, 2004). However, the power in a network with multiple stakeholders is distributed across the structures, which will be expanded on in the discussion section. Still, researchers are insiders in the research field, which brings disadvantages, such as a lack of objectivity and making false assumptions (DeLyser, 2001). We mitigated this through a clear theoretical framework and triangulation to support the validity of our claims. Further, we asked the participants to give us their opinion on the findings, seeking consensus on understanding of what happened throughout the course of the research. To secure the ethical standards of the research we applied for and were granted authorization by (Norwegian) Council for Research Data according to the ethical standards that include participant consent, anonymization, and secure data handling. The patient involvement was organized through informed consent, confined to the space of the Sorri rehabilitation center, also limited in time on two meetings, as well as monitored and led by therapists. The social and clinical value was in understanding how academic cooperation and research can contribute to customizing assistive technologies for patients. The ethical standards for patients were insured through a previously agreed general terms between Sao Paulo State University and Sorri rehabilitation center.

Findings

Example 1 – designing dynamic orthosis for a stroke patient

Visiting the rehabilitation center, the student group was presented to a 29-year old male patient. He comes to the center for weekly rehabilitation program to regain some control over the left side of his body, although he is right-handed, which was paralyzed by the stroke. The event caused significant changes in his life, preventing him from doing his work as the owner of a local farm. Though struggling to walk and grip with his left hand, he smiled and continued his exercises with humor. The group interviewed him, trying to gain insight into his perspective of the condition. After the meeting, the therapists shared their understanding of the process. They expressed that they were satisfied with his recovery, but that the process would have been more fruitful if the patient was more persistent in using his limbs rather than finding workarounds by employing the functioning side of his body. This directed the group to discuss how to engage the left side of the patient's body. After the stroke, the patient's left hand was frozen in position of a permanent half-grip, disabling it for use in ordinary activities. The group discussed the potential of augmenting the opening of the hand so that the patient could perform a gripping motion. The group developed a mockup made of tape, paper, and thread, which illustrated the function but was not functional. They designed the prototype in detail using the modelling software, which enabled them to define the shape and size of the rings, as well as thread openings. They 3D printed a series of finger rings in different sizes for each finger. Further, the students assembled the prototype on site to fit the patient's finger sizes. The prototype took the form of a dynamic orthosis, which opened the hand by pulling the nylon thread. The students tested the opening principle successfully with the patient (Figure 1). The therapist noticed that the dynamic orthosis did exactly what it should, but that it would be difficult to make the patient use it outside of the rehabilitation center.

Figure 1. Dynamic orthosis assembled and tested with the patient

At the beginning of the project, the group discussed the potentialities of the 3D print technologies and through a series of meetings worked out the customization aspect of the orthosis as a potential of the 3D printing technology. In this example, the 3D printing technology amplified the learner's ability to produce a geometrically complex and a precise prototype without having to master the usage of different kinds of machines. By translating their paper-tape-thread mock-up into a virtual model, their field composition changed, and their sense of manageability of the task was elevated: "We would never be able to make this complex prototype in such a short time without a 3D printer." They successfully pivoted the 3D printing into assistive technology manufacturing. It also was meaningful to them as it directly addressed the most noticeable issue of the case: "The user's hand is the most obvious problem, even though he doesn't explicitly complain about it." However, they did not fully comprehend the issues the user had. For the user, the assistive technology amplified his ability to open the hand but also amplified his awareness of his immobility. The technology was not transparent to him as it was not meaningful; he could not see the value of it in his already established routines where he used compensation strategies such as using his knees to grip objects and his right hand to manipulate them; therefore he failed to pivot. As the learners were mounting the dynamic orthosis prototype, they noted: "He doesn't seem to be commenting on this as he did before." Also, therapist noted: "It will be difficult for me to convince him to use this outside of the hospital." The assistive technology was not transparent to this patient, and the fusion strategy failed because it was not meaningful and possible to sediment into his daily routines. However, the therapist recognized a purpose for this object: "I think we could use it as a part of the gripping exercise that we already do." In her comprehension, when fully functional, this assistive technology could be sedimented into her work routine.

Example 2 – device for stimulating movements for a toddler with Cornelia de Lang syndrome

The group entered a small room and was greeted by the staff, a two-year old boy, and his mother. The conditions of the syndrome had caused a diminished growth of his upper limbs. Their low muscular extension had caused a shortening of his back muscles. Both of his arms end with one finger, which has a bone and muscular structure. The mother and the therapist were playing with the boy, challenging him to use his limbs slightly outside of his comfort zone with each interaction. The therapist, in particular, engaged the boy's limbs through toy button games, exposing the limbs to different materials with the goal of teaching him to explore the world with his limbs and decrease his fear. The patient was struggling but was showing motivation and a willingness to try. After the interview, the group immediately discussed how they could create a device that could facilitate the boy's limbs in his explorations. Through several iterations, the group decided to prototype a penholder, which could be used in two ways in order to stimulate different movements. The first way would allow the boy to hold the pen with his elbows. The holder was therefore shaped as a soft pillow (see Figure 2). The second way was by mounting the holder to the arm strap. The group saw the potentiality of 3D printing in materializing complex geometry that could adjust the artefact for two different configurations. They 3D printed the rigid parts of the product and used neoprene and elastic bands for the soft parts. In their testing, the user failed to use the product in either way. However, the boy showed a desire to draw, and the therapist and mother helped explore ways of doing it. With suggestions from the group, they came up with novel ways to allow the boy to draw.

Figure 2. Left, the initial pen concept; right, concept developed through testing

The group initially came up with two human-technology configurations stimulating two types of movements. As they developed these configurations, they discussed how to merge them into one product. The goal was to simplify the logistics of the product when not in use. The group agreed that they wanted the product to be merged into one object so that it would be difficult to lose separate pieces. The ability to manage this was accomplished through the capability of the 3D printed parts to be merged through complex geometric mechanical connections. However, the group exposed itself to the competing configurations as amplification of logistics and function collided when forming the technology. This made the project less manageable and difficult to comprehend for a given time frame.

As the group members tested their product, it became obvious that the patient was focused on the paper and was determined to use the product. A learner noted: “He is really persistent.” However, the object’s geometry and the looseness of the strap prevented the patient from performing his task. Thus, the technology was opaque rather than transparent. It prohibited rather than amplified the user’s already diminished abilities. However, both the parent and therapist saw the activity as meaningful and possible to sediment into patient’s daily and therapeutic routines. They used parts of the product and tried different physical configurations between the patient and the technology before it was temporarily stabilized in the form of a shoulder strap (see Figure 2).

Example 3 – redesigning a wheelchair armrest for an immobile patient

The group entered the room and was greeted by a 67-year old man and his son. After the stroke that paralyzed his left side, the man became dependent on his wheelchair. This, coupled with severe pneumonia, has significantly reduced the man’s autonomy. Recently, the patient has regained control over self-care in his daily routines, such as shaving and combing his hair. The conversation moved from the dread of daily routines and exercises in the rehabilitation toward his life before the stroke. The group noticed a shift in his attitude when he talked about his experiences when being with his son for leisure and fishing. After discussing a few concepts, the group decided to focus on how to facilitate the patient’s use of the fishing rod with only the right hand. The group decided to develop a mounting table for the wheelchair that could be set up when the patient goes fishing with his son (see Figure 3).

Figure 3. Wheelchair table with mounted fishing rod

The table included a fishing rod holder and a place for a mobile phone and a drink. The group produced a series of digital models but struggled to design a model that could be 3D printed with the desired mechanical properties. Finally, the group produced their prototype in fiberboard. The group tested the placement of this prototype on the wheelchair with the fishing rod, and the patient showed genuine excitement. The therapist commented that it might not be ideal to make the wheelchair too comfortable, but rather to try to make the patient get out of the chair, but that it was still positive as it would make him more active and want to go on fishing trips.

Early in the process, the group explored 3D printing potentialities to produce a complex geometry by printing only one part. They used most of their time designing their digital model with the expectation to 3D print it. As the project progressed and the group learned more about the technology, it became obvious that it would be difficult to produce an object with satisfactory mechanical properties by 3D printing the part. In this example, the technology inhibited learners' ability to manufacture the prototype. However, the process of preparing a digital model for 3D printing seemed to be crucial for changing their field composition: "We definitely would not explore this geometry if we were not supposed to 3D print it." Another student put it in these words in the final presentation: "We haven't 3D printed the model, but it helped us to think functionality through 3D print." Finally, the group had to use an electric jigsaw to produce their prototype from fiberboard and polyvinyl tubes. They failed to pivot 3D printing into assistive technology and fell back to sedimented practice of accomplishing design prototypes by using series of workshop tools.

The group tested the prototype with the user who showed genuine interest: "When can I use this?" The product amplified the user's ability to use an already sedimented technology, a fishing rod. Therefore, it felt manageable and familiar. Further, the technology allowed the patient to spend more time with his son, making the technology meaningful and possible to sediment in already existing practice. On the other hand, this technology, even though comprehensible for the therapist, did not give any meaning and could not be sedimented in her practice: "The goal of the assistive technology for the rehabilitation should be exercise of the disabled part of the body."

Discussion

This research setting was characterized by multiple human-technology mediations. First, learners and technologies mediated to create new assistive technologies; and second, they did this to mediate between newly-conceived assistive technologies and the patients. However, the mediation happened on several other levels that were not analyzed in this study. The newly-designed assistive technologies mediated students' learning with the academic staff, new rehabilitation practices to therapists, and altering relationships between patients and their caregivers. Finally, the mediation happened between teachers and 3D printers as the machine afforded conducting practical projects with multiple outcomes in a single manufacturing process. This allowed teachers to spend less time on teaching skills and simplified health and safety procedures for the students.

Likewise, pivoting happened for everyone involved in this learning situation as technology became transparent to them. Throughout this four-week course, all of the groups managed to gain transparency over and envisage the potentiality of the 3D printing technology. However, they all experienced challenges in materializing assistive technologies, as it became transparent for some actors and opaque for others. In the first example, learners successfully pivoted 3D printing technology into a orthotic technology transparent for the therapist but not for the patient, while in the third example, exactly the opposite happened. In the second case, students failed to stabilize the drawing device for the patient and had to return to a multistable prototype to explore new patient-technology configurations.

Implications for design and pedagogy

From the postphenomenological perspective, learning and designing could be defined as transformation that happens as an outcome of human-technology mediation, which is reciprocal. Learning and designing encompasses how humans gain agency with technology; how they stabilize and sediment it; and how they see, vary, and decipher pivoting aspects in technologies' potentiality. Design is then the practical and material outcome of this learning.

Learners are constrained and enabled by technologies' affordances, which informs their field composition. Field of awareness and field composition should be the central pedagogical topics in the context of the postphenomenological view on pedagogy. Pedagogy should provide answers on how to educate learners who have a broad field of awareness and who can both adopt and abandon field compositions provided by technologies. This is crucial to learners' resilience and integrity.

Integrity can be seen as a learner's ability to use the field of awareness to critically assess field compositions in her environment and choose ones with sustainable outcomes. Resilience can be seen as a learner's ability to switch field compositions, pivot, explore technological potentialities, and stabilize and sediment sustainable practices. The focus here is not on the learner's reframing of the problematic situation or applying design methods; rather, it is on the exploration of relations, mediations, and making choices. The other more obvious role of pedagogy is to provide human-technology networks that are unlikely to emerge in business research and development environments, which can facilitate and nurture their integrity and resilience. From that perspective, one cannot teach, for example, inclusive design or assistive technologies outside of the relationships made by patients, therapist, and designers. This relational view on design studio pedagogy also transforms the role of an educator as a "master practitioner" who provides critique (Schön, 1985, pp. 10-17), to that of one who teaches critique.

Sterling (2010) has already provided a theoretical framework for this perspective on pedagogy in his description of resilient learning in relational ontology:

> *Learning is seen as an essentially creative, reflexive and participative process. Knowing is seen as approximate, relational and often provisional, and learning is continual exploration through practice, whereby the meaning, implications, and practicalities of sustainable living are continually explored and negotiated. There is a keen sense of emergence (unplanned ideas, outcomes, and dynamics arising from the learning situation) and the ability to work with ambiguity and uncertainty. Space, reflective time, experimentation and error are valued to allow creativity, imagination and cooperative learning to flourish. Inter- and trans-disciplinarity are common, there is an emphasis on real-life issues and the boundaries between institution and community are fluid. In this dynamic state, the process of sustainable living and developing resilience is essentially one of learning, whilst the context of learning is essentially that of sustainability. (Sterling, 2010, p. 523)*.

Conclusion – an expanded conceptual framework for resilient learning with technologies

This study found that resilience among the participants emerged even in a situation that was disruptive for inexperienced students. It also showed how learners struggled to adopt new technologies, as well as to recognize and take into account multiple potentialities and implications for multiple stakeholders in the learning network.

The report “Education 2030” by OECD (2018) addresses the disruptions and opportunities that innovative multistable technologies with high potentialities, such as, for example, artificial intelligence and mixed reality, present to future learners. Further, it addresses the acceleration of technological multistabilities (Riis, 2015) that will present students with ill-structured problems and a threat to environment and well-being. It has become urgent to address this issue in an age where knowledge and skills are rapidly rendered obsolete by accelerating multistabilities. Education could benefit from multifaceted discussions on this topic.

The presented case study has expanded vocabulary concerning learning with technologies by further addressing learning for resilience and shedding light on the challenges of educating resilient learners. It illustrated a practical pedagogical and theoretical approach to learning for resilience in these new circumstances from the perspective of relational ontology and postphenomenology. From this perspective, intended learning outcomes by means of knowledge and skills (European Commission, 2018) might benefit from being formulated in more relational terms. These formulations rely on describing learning environments or technologies that learners have experienced and their role in it. Accordingly, the technological education might besides being knowledge and learner oriented, provide more attention to facilitation of inspiring socio-technological environment. In this environment, learners can become familiar with their own agency, integrity, and resilience. In a multistable and unpredictable setting, where knowing is approximate, relational, and provisional, only their own sense of agency, coherence, and persistence can allow them to navigate complexity. While there is little space to do this in some design studio educational settings, most of the learners will unfortunately experience this way of learning when they first enter the job market.

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Book Review
Mentoring Design and Technology Teachers in the Secondary School: A practical guide
Suzanne Lawson & Susan Wood-Griffiths (Eds.)

Reviewed by Stephanie Atkinson, University of Sunderland, UK

Mentoring Design and Technology Teachers in the Secondary School: A practical guide is one in a series of books providing an evidenced based approach to advice for those mentoring beginning teachers. Each book provides subject-specific practical guidance to reinforce and inspire mentors to develop their understanding of different aspects of their role, as well as to encourage them to explore subject-based issues that mentees may encounter in the course of learning to teach.

Mentoring Design and Technology Teachers in the Secondary School: A practical guide, is written in a readable style and is made up of a short introduction that offers useful advice on further related readings and an overview of the thirteen chapters that follow. Chapter 1 is written from a generic perspective while the remaining twelve chapters are subject specific and are written by authors who are from a variety of D&T disciplines. Each author has a wealth of experience of teaching their discipline in the UK and has been a skilled mentor of D&T trainees over a number of years. Each chapter covers a unique aspect of the D&T curriculum, however, they have been written in such a way as to make the content relevant to the needs of mentors and mentees across the various disciplines of D&T activity.

The structure of the thirteen chapters is similar. Firstly, the authors challenge mentors to reflect critically on theory, research and evidence concerning their own knowledge of, and approaches to, mentoring in the context of the specific topic under discussion in their chapter. Secondly, the authors set out to explain how mentors can help beginning teachers to develop their practice in the context of the targeted subject matter. Several well-designed tasks are provided in each chapter and while some of the activities are designed to encourage individual reflection by either the mentor or the mentee, others provide activities that can be worked on by both together. Each chapter is well supported by pertinent literature and at the end of each chapter suggestions for further relevant reading are included.

Chapter 1: Models of mentoring
Gill Golder, Alison Keyworth and Clare Shaw

In Chapter 1 Golder et al. provide a well-structured, clear and readable chapter that begins with an in-depth discussion of various generic definitions of mentoring. The teaching context and how it will influence the way a mentor acts is then reviewed. After explaining the plethora of existing effective mentoring models supported aptly by relevant literature, they compare and contrast three developmental models and suggest how these could be used to support the complex role of a mentor. The chapter includes seven well-constructed developmental tasks to further expand the reader's understanding of the chapter's content. The chapter finishes by admitting that mentoring is a complex and demanding task although the reviewer believes that Golder et al. have successfully indicated how a mentor can develop the necessary skills required to enable them to have a positive impact on the development of any mentee under their care.

Chapter 2: Understanding yourself-beliefs, values and attitudes how your experiences influence your approaches to mentoring

Alison Hardy

The start of this chapter focuses on the formation of a mentor’s own beliefs and values in terms of education and more specifically in terms of D&T teaching. A section concentrates on explaining the origins, influences and consequences of beliefs and values in association with various aspects of D&T, citing family influences, personal context, experiences of how one was taught, as factors that shape a person’s beliefs and values and how these impinge on the teaching approach adopted by the teacher, whether experienced or beginner. Using the author’s own research to support the discussion the next section of the chapter examines the wide range of different values that can be attributed to D&T. The likely influence of beliefs and values on a mentor’s approach to mentoring are also highlighted, alongside explaining that the values a mentee attributes to D&T are likely to be different to those of the mentor due to differences in age, experiences and gender. The four tasks spread throughout the chapter each target an aspect of the themes discussed, by asking the mentor to question their own beliefs and values and to compare them to those of their mentee.

Chapter 3: What knowledge, understanding and skills do mentors of new D&T teachers need?

Ruth Seabrook

This chapter explores the mentor’s understanding of their own personal D&T subject construct and practice through well researched exemplification, discussion and tasks that encourage the necessary reflection to achieve this aim. Seabrook leads the discussion towards assisting the mentor to enable the beginning teacher to understand their own D&T subject construct in order that they can audit their developing subject knowledge and identify the core skills necessary to become a reflective teacher, with the intention of enabling continued learning and knowledge growth, which is so important for all D&T teachers throughout their careers.

Chapter 4: Helping new design and technology teachers get the big picture: understanding the fundamental nature of design and technology

David Barlex, Nick Givens and Torben Steeg

In a comprehensive, well referenced manner this chapter explains why D&T is an essential component of a balanced education for all students in terms of *“ the ‘why’ and the ‘what’ of teaching D&T”* (p.50). Threads run through the chapter to support the authors beliefs that the learning intentions of the subject are to develop technological capability and technological perspectives. The chapter includes wide ranging discussions concerning the purposes and nature of the subject with specific sections on the complexity of designing, the different philosophical positions with regards to technology and the significant ideas that underpin the nature of the subject. Barlex et al. identify these in terms of knowledge of materials, manufacturing, functionality and design, with a section on knowledge of critique regarding the impact of the subject. The eight tasks dispersed throughout the chapter provide sound questions that link the chapter’s content to the mentor’s role supporting beginning teachers of D&T to be clear about why the subject is included in the curriculum.

Chapter 5: Helping beginning design and technology teachers to analyse and develop knowledge, skills and understanding of food preparation and nutrition

Jacqui Vaughan and Dave Howard

This chapter focusses on the role of a mentor in a food related area of the curriculum which as the authors point out has a predominance of practical activity involved in its delivery. An area in which the teacher needs to be very mindful of safety as well as the learning experience. The authors explain that a mentor's role is not a static one, they point out that the role will change as the mentee becomes more confident, self-assured and independent. They make clear that achieving the correct balance in terms of encouragement is vital, as too much challenge and stimulation can overawe and alienate a beginning teacher. They detail the road to becoming a competent, reflective food teacher explaining the key areas for a mentor to focus upon. Themes such as timing, instruction, support to pupils, assessment and managing learning are discussed. Six well-designed tasks provide starting points for the mentor, who through effective modelling and support can enable the mentee to develop a sound professional identity. The activities also potentially raise questions for the mentor to consider about their own practice. The authors explain that the relationship between mentor and mentee can, and should be symbiotic and mutually beneficial.

Chapter 6: Helping new D&T teachers to analyse and develop knowledge and understanding of design and technology (product design)

Matt McLain

McLain begins by describing D&T as an ever changing, multi-material, multi-activity aspect of the curriculum. One, unlike some other areas of the curriculum, where teachers are required to update and develop their range of subject knowledge throughout their teaching careers. McLain's chapter sets out a well researched series of sections to help answer fundamental questions such as: 'What is knowledge?' and 'What is teacher knowledge?' before going on to discuss the complexities of D&T knowledge and articulate four key D&T challenges that he believes new D&T teachers need to understand, alongside the all-important, knowing how children learn. He explains how all beginning D&T teachers will have sound subject knowledge in some areas, basic elements of complex knowledge that they have forgotten, and gaps that include topics not studied recently, or at all. He also provides advice for mentors on the short-, medium- and long-term needs of new D&T teachers. The six tasks provided are carefully designed to help the mentor and mentee understand and overcome the challenges concerning subject knowledge raised throughout this chapter.

Chapter 7: A skills audit: identifying gaps in beginning design and technology (D&T) teachers' subject knowledge, skills and understanding

Suzanne Lawson and Susan Wood-Griffiths

Chapter 7 leads on from the previous chapter by focusing on the auditing of skills and the identifying of gaps in beginning teacher's subject knowledge, skills and understanding. It concentrates on helping a mentor to know how to facilitate such an audit by developing auditing tools based upon published guidance. Lawson & Wood-Griffith suggest ways of overcoming what can be a debilitating auditing process by building on the beginning teachers strengths and showing them what they can achieve rather than focussing on where they are at, at the time of the audit. The author's aptly use Shulman (1986) and Ball et al. (2008) to support mentors' understanding. Helping them to explain to beginning teachers how within D&T their own core knowledge should be structured and organised using the seven tasks provided to help develop and overcome deficits in understanding. They also provide pertinent case studies of three trainee teachers to illustrate how contacts outside of the classroom can benefit the beginning teacher, the mentor and pupils learning.

Chapter 8: Helping D&T teachers plan, deliver and evaluate lessons

Louise Beattie, Susan Lawson and Susan Wood-Griffiths

This chapter is specifically targeted at the mentors of initial trainee D&T teachers. It provides advice for mentors on how to develop their mentees ability to become reflective practitioners in terms of planning, delivery and critically evaluating their teaching and pupils' learning processes. It explains clearly how a lesson plan should not be seen as an isolated product but as part of the whole learning and teaching process. The authors' rightfully argue that it is vital that this process is learnt during initial teacher training and not left till trainees become beginning teachers. The chapter content sets out to enable the mentor, with the mentee, to reflect on the complex processes that underpin effective lesson planning. It provides practical suggestions based on using the mentor's own planning, teaching and reflection practices. The chapter also provides key questions that can be used to aid the trainee's design and use of lesson plan templates. Further sections discuss managing feedback and using data and assessment to inform planning and teaching. Tasks throughout the chapter are there to provide mentors with useable ideas for developing this vital aspect of a mentee's teaching.

Chapter 9: Helping design and technology teachers to plan practical activities (including health and safety)

Jane Burnham

Chapter 9 emphasises the importance and benefits of practical activity found across all D&T disciplines. It identifies strategies that mentors can use to support beginning teachers to manage such activities, and it uses case studies to illustrate and pose questions for beginning teachers to think about. The benefits of using support staff and working collaboratively in practical situations are identified and explained. There are also sound sections that target the professional duties of a teacher to ensure a safe working environment for all learners. The significance of health and safety legislation and guidance to support safe management of this sometime challenging and demanding aspect of the curriculum are also explained. Eight carefully constructed tasks provide activities that mentors can use with the beginning teachers to expand on each of the chapter's themes.

Chapter 10: Observing design and technology teachers' lessons: tools for observation and analysis

Sarah Davies

This chapter focusses on the mentor's role in using classroom observation to develop the necessary skills and understanding of beginning teachers of D&T. The two purposes of observation; to assess competence and create data for analysis and reflection, are debated with reference to pertinent literature. Davies refers to DfE guidelines (2018) where classroom observations are suggested as a tool to help beginning teachers with seven key aspects of their role as a teacher. Davies goes on to show how data from classroom observations can form the backbone of crucial formative and summative feedback – feedback that can encourage dialogue about practice that improves practice. Sections of the chapter look at the process of classroom observation in terms of preparation for the observation; recording the observation; during the observation and after the observation. The chapter also targets developing a mentor's awareness of alternative approaches such as the use of video, which research has indicated can facilitate more authentic, beneficial, critical reflection and ongoing professional learning than traditional methods of observation. Seven Tasks linked to each section of the chapter provide sound activities, which in some instances are for the mentors to use to develop their own thinking and mentoring skills, and on other occasions they are written as tasks for mentors to use with the beginning teachers.

Chapter 11: Supporting the beginning teacher through professional conversations

Alison Winson

Chapter 11 targets the ways in which the mentor can support beginning D&T Teachers through professional conversations. Winson starts by referring to her earlier publication on the subject of feedback which indicated that, the language chosen and the questions posed were all crucial to the successful mentoring of new teachers. The chapter goes on to discuss initial professional conversations and post lesson conversations. These are debated in terms of when to hold such conversations and what they should look like. Target setting is also examined. The chapter concludes with a discussion on how a good mentor will also provide challenge and support for future aspirations. Eight tasks that provide the mentor with scenarios that can encourage professional conversations at various times in a new teachers career are a useful addition to the chapter’s content.

Chapter 12: Risk taking in the classroom: moving teachers forward from pedestrian to innovative practice

Dawn Irving-Bell

This chapter concentrates on identifying ways a mentor can proactively help in the long-term management of the beginning teacher’s personal growth and development. Benefits of successful risk taking are firstly discussed generically followed by the meaning of taking risk, specifically in the context of D&T. Encouraging risk taking, getting the balance right, identifying suitable challenges, and developing strong professional relationships are followed by a useful case study about the importance of good communications. A number of practical strategies, frameworks and scaffolds are then discussed supported by tasks for the mentor and mentee. The final section considers when mentoring is outside the mentor’s comfort zone. Irving-Bell explains that with the broad range of subject disciplines combined in D&T quite often a mentor can be required to support a mentee from a different D&T discipline than their own, or the mentor can be requiring the mentee to work within a D&T material area that is new to them. Once again a case study is used to clearly illustrate such issues and exemplify how they can be overcome. Irvine-Bell provides useful resources especially in the areas of supporting ‘stretch and challenge’ for beginning teachers.

Chapter 13: A stakeholder view of mentoring – reflections from those who mentor and have been mentored. What lessons can be learned?

Suzanne Lawson and Susan Wood-Griffiths

The final chapter, written by the two editors of the book, is based on collected views and experiences of mentors, mentees and experienced teacher educators and sets out to: stimulate, counsel, structure and address problems associated with mentoring. It starts by describing the relevance of each of the previous chapters and then goes on to discuss in detail a range of perspectives from other literature on mentoring, while also making appropriate references back to various thoughts and ideas presented in earlier chapters. This is followed by sections on understanding the impact of mentoring both on the mentor and the mentee and the implications of stress from the perspective of workloads for both the mentor and the mentee. The authors, backed by relevant research also discuss how an excessive workload has been shown to be the most common reason for beginning teachers leaving the profession. They explain the importance of a mentor helping a mentee in terms of time management and using non-teaching time effectively. A final section provides a considered view on the qualities of a good mentor and reviews the reasons given by selected mentors as to why they agreed to take on such a time consuming but rewarding role when they were already working under increasing pressures and limited time.

Reviewer's Conclusion:

As stated at the start of this review *Mentoring Design and Technology Teachers in the Secondary School: A practical guide* provides excellent subject-specific practical guidance that can reinforce and inspire mentors to develop their understanding of different aspects of their role, as well as encourage them to explore subject-based issues that mentees may encounter in the course of learning to teach. Although the book is written by authors all based in UK educational institutions the challenges and opportunities discussed in each chapter are not confined only to those mentors or mentees based in the UK. I believe that this book can provide food for thought and support for all those wishing to become effective, reflective mentors wherever they are supporting the next generation of D&T teachers.

References

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