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Editorial 27.1

Back to the future

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

Welcome to the first issue of the journal for 2022. Looking back to a year ago, to the first DATE editorial of 2021, we hoped that we were entering the final chapter of the pandemic, and were speculating about how things might change and what future design education research may focus on. Now it appears that rather than conquering the pandemic we are being advised to 'learn to live with Covid' and work around it as best we can, using our own judgement and personal responsibility. Those hoping for an official roadmap out of the pandemic, or looking for roads to recovery back to those pre-pandemic times of 2020 may be disappointed. External stakeholders suggest that education, in particularly HE, requires a radical rethink, with many universities worldwide beginning to adopt a "future-back" approach to ensure future growth according to the Ernest and Young 2022 report *Are universities of the past still the future?* (https://www.ey.com/en_sy/education/are-universities-of-the-past-still-the-future). As our special issue 26.4 from December 2021 clearly demonstrated, the design education community will continue to study the effects of the previous two years on our practice and propose new ways of working, learning and teaching, and look to the future with cautious optimism. To paraphrase everyone's favourite Hollywood physicist Emmett Lathrop "Doc" Brown, PhD, "*Roads? Where we're going we don't need roads".*

Anyway, back to the future, or rather to the contents of this current issue, which includes eight research articles and a book review. The first seven research articles report directly on research in design and technology learning and teaching activities around the world, in areas such as collaboration, communication, equitable learning, core skills, digital/traditional mediums, and audio feedback with the final research article looking at developing new curricula, in this case focusing on sustainability, within institutional frameworks.

The first research article focuses on the way that designers and design students collaborate and communicate in design processes. In *Creating new 3D forms in collaborative product design***,** Weishu Yang from University of Helsinki, Finland & Yunnan University of Finance and Economics, Kunming, China, and Henna Lahti and Pirita Seitamaa-Hakkarainen from University of Helsinki, Finland present research from an exploratory case study on students from three design disciplines (interior design, product design, and graphic design) engaging in a re-design workshop developing 3D product forms. The paper seeks a clearer understanding of the role of co-evolution in student design teams made up of different disciplines, and how a mix of domain-specific skills can help to frame the problem and drive the co-design of a solution. Following a workshop on Rapid Modelling Techniques a structured design brief was given and the student responses and design activities were observed, with flow charts created to log the processes. The duration and distribution of activities varied between the groups with considerable differences in emphasis on design stages across the disciplines. While all of the groups produced a workable design that met requirements, the processes they used to get to their endpoints were quite unique. Some focused more on their previous user-centred design domain-specific knowledge, while others concentrated more on the visual aspects of the form or the overall functionality of the model. While the authors state that there is a need for future studies to deepen the analysis of problem-solving co-evolution between different design fields and professional experiences, it is clear that the students involved in the workshop gained a great deal from their cross-disciplinary experiences of product co-design and co-evolution.

A second study from Finland exploring collaboratory design processes is presented by Noora Bosch, Tellervo Härkki, and Pirita Seitamaa-Hakkarainen (University of Helsinki). In *Design Empathy in Students' Participatory Design Processes* they present research conducted with 14-15 year old students to explore how design empathy manifested in their design processes. Their brief '*co-design and make an e-textile product for kindergarteners according to their wishes and needs*' was used to explore the end user related considerations of the students and signs and dimensions of empathy. The authors explore how design students can develop a more participatory and collaborative design process in order to make more meaningful design solutions, and they suggest that there is little research in this area at primary and secondary education levels. Through a textile-based brief the secondary level students took the role of participatory designers in front of the pre-schoolers, with the teachers and the kindergarteners being considered end users. 12 sessions were used to develop the design process following the Double Diamond model, and the design outputs are analysed in terms of product-centric and human-oriented considerations and mapped against a design empathy framework. While it is evident that the students could show empathic design skills in their work, and the interaction with the end users has certainly helped to engage and motivate them, there are still difficulties with defining what empathy is and how it can be identified and developed. Clearly there are many opportunities for further work in this area of participatory design at primary and secondary level, and the authors suggest that community based participatory projects such as this may be particularly relevant for improving girls' motivation and engagement in wider design technology and STEAM activities.

A further article exploring gender and equitable learning comes from Dhriti Dhaundiyal from Doon University, India and Shruti Dhaundiyal from Cambridge University, UK. In *Gendered Pathways in Design Education: Findings from a Public University in India*, they present research on how the emergence of 'industrial' and 'communication' domains in design, or 'hard and soft design' has contributed to the creation of gendered educational pathways in Indian design education. Through an analysis of Indian design education and it's recent growth in scale, and the creation of categories of exclusion noted by other researchers the authors note that there remains the perception that technology education is a male domain. The reasons for lower female enrolment and technical design gender bias however are more complex, with the authors drawing from 5 years of data and finding evidence of links with social class, income and geographic location and choice of educational pathway. They also found gender bias in the design briefs used in programmes but also in societal conventions and curricular expenditure. While the work is focused in one city in North India the authors suggest that there may be benefits from extending this work to other regions, and there is plenty of food for thought for those of us interested in studying gendered pathways in design education. The suggestion that exposing students to ‘hard’ design subjects, with their more technical and systemic terms and their greater focus on technology, at an early foundational stage of their learning may help to lessen gendered pathways in design education is of particular relevance to those engaged in primary and secondary education. This 'hard' and 'soft' design dichotomy is global, with women under-represented in 'hard' design areas such as product, automotive and furniture design and over-represented in 'soft' design areas such as fashion, jewellery, graphic and service design.

The fourth research article is *Landing your first job in Creative Technologies: Soft skills as Core skills* by Ricardo Sosa, Rajiv Rajusha and Amabel Hunting from Aukland University of Technology, Aotearoa New Zealand. It explores the demand for employability skills and the need for greater student-industry understanding and relations through ongoing dialogue between industry and academia. The authors note that Industry 4.0 will require a transdisciplinary skillset to prepare graduates for jobs that don’t currently exist, and this research stems from a desire to develop these skills in design students and graduates with the support of relevant external stakeholders. It is evident that the types of roles and size and structure of companies play a key role in the development of a transdisciplinary skillset, with a smaller startup company perhaps providing more opportunities in this regard, offset perhaps by a lack of mentoring opportunities. Upskilling in employability skills is a key benefit identified from internships or company placements, with some discussion on how students can be encouraged to develop the set of core skills necessary to make the most of these opportunites. Reframing ‘soft’ skills as ‘core’ or ‘industry’ skills, and utilising and integrating more employability input from industry are two of the key takeaways. The authors note that ongoing disruption to the creative industries in New Zealand, and the related moves towards more isolated working and automation of creative tasks, will require a more longitudinal view of this area, but there are many useful insights into how academia can further engage further with the creative industries here.

An Exploration of the cognitive processes of design teams to inform design education and practice by Louise Kiernan, Ann Ledwith, and Raymond Lynch from University of Limerick, Ireland aims to map and understand the cognitive processes employed during multidisciplinary team interactions. While much emphasis is traditionally placed on the role of creativity in design thinking, the authors suggest that other cognitive modes such as knowledge processing, critical thinking, and metacognition are engaged in more frequently in creative design teams. They point out that while creative collaboration is key to design studies, there is no agreed approach to how interdisciplinary teamwork should be implemented, either in or out of a studio environment. Through the development of 4 case studies the cognitive processes of a range of participants are analysed and mapped across the design process, showing the variation in knowledge process distribution across the design phases. Findings show that creative thinking only accounts for 7% of overall cognitive activity in the design process, suggesting that more focus could be placed on the other aspects of design thinking among educators. The authors make recommendations for those leading student design teams, especially around promoting focus through careful facilitation of the team interactions, and through development of productive dialogue with tutors matching the thinking processes to the project phase to reinforce and scaffold the resulting creative conversations. This may help to move focus from the final project output to the design process, helping to promote a greater emphasis on a team's creative journey.

The research article from Luis Alfonso Mejia-Puig, University of Florida, USA, Hugo Dario Arango, Universidad Icesi, Columbia, and Tilanka Chandrasekera Oklahoma State University, USA, *Perception over the use of traditional and digital mediums within the design process: A questionnaire study on design students* explores student's perceptions of traditional (non-digital) and digital mediums in the design process in Latin America and North America. A questionnaire was used to collect data from second year design undergraduates in order to better understand their preferences in design mediums at different stages of the design process. While traditional techniques such as sketching and low fidelity models are used in the early stages, digital tools typically take over in the later stages of the design process, but new digital tools are now allowing a purely digital design process, although there are benefits and challenges associated with both. While there are clearly benefits from mixing traditional and digital methods, the students demonstrate clear preferences for digital methods even when they can be less intuitive as they are more time efficient and can give increased group interaction, especially when delivering in a blended learning environment. The future directions suggested by the authors raises the issue of engaging and maintaining student interest and satisfying their needs, and this is certainly a key driver for the move to a more digital design curriculum, but it is clear that current digital tools are often not as intuitive, immediate or engaging as the traditional methods that they are rapidly replacing.

Our seventh article *Audio feedback in distance design education* by Derek Jones and Clive Hilton from The Open University, UK, discusses the use of a blended feedback model using a mix of audio and summary text in place of the usual written-only feedback in a distance design education setting. The motivation behind the study was a concern that students were neither attending to feedback or acting upon it, a particular issue with distance learning when there may be less personal connection between tutor and student. The greater emotional connection with audio feedback is discussed, along with the timing and quality of the feedback itself. While the students clearly gained a great deal from both written and blended feedback, the audio feedback seemed better suited to critical design feedback, with students feeling that it was more direct, honest and personal. One of the key issues was that of motivation, with a tutor enthusiasm being more evident in the audio rather than written form. A blended approach was found to be the preferred option, with a critical but supportive balance helping to replicate the student experience hopefully found in a well-run traditional studio-based critique, but with the added benefit of being recorded in a summary written as well as audio form for later actioning and feed forward.

The final research article in this issue shifts our focus back to the DATE 26.3 E&PDE Special Issue from late last year with an article that first appeared in abridged form in the Engineering and Product Design Education (E&PDE) conference, 2020. *Exploratory study on the role of institutional frameworks on engineering curricula evolution: A case study on transition towards sustainability* by Lou Grimal, Jules Baudry, Pelgrim Charraud, Rémi Céret, Nadège Troussier from Université de Technologie de Troyes, France, explores the challenges of developing new courses within an existing institutional framework, especially those dealing with rapidly changing phenomena such as socio-ecological issues, in a French higher education context. While the authors acknowledge that the integration of sustainability into engineering studies is not new, they suggest that a better approach would be to move from a more material and environment focused approach to a more multi-dimensional systems level model. Through a one day student-led workshop the authors show how many participants had difficulty in positioning themselves and their work within the French national accreditation process for engineering curricula, and that the framework was too rigid to allow them to fully explore their sustainability agendas. Although the number of participants was low, the article raises many relevant issues with regard to the implementation of systems level thinking in curricula, in particular the complexity of the issues and the discipline specific language and framing of many of the issues. It also raises the issue of whether rigid internal or external frameworks for accreditation of education programmes stifle innovation within individual courses and modules, and whether they constrain new ways of thinking and dealing with the emerging socio-economic and environmental challenges of the future.

Finally, in addition to the research articles, we have a book review from Ritesh Khunyakari from the Tata Institute of Social Sciences, Hyderabad, India of the recently published *Design-Based Concept Learning in Science and Technology Education* edited by Ineke Henze & Marc J de Vries, published by Brill and part of the *International Technology Education Studies* series.

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27.1

Creating new 3D forms in collaborative product design

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Abstract

In collaborative design settings, designers communicate and explicate their ideas visually and verbally in order to reach a shared understanding. The verbal exchanges of group members engaged in a joint design task provide rich data regarding the design activities being undertaken by the group members. In addition, sketching and modelling are recognized as essential for designers to examine and produce design ideas at the very beginning of a re-design process. This exploratory case study focuses on collaborative design activities and problem–solution co-evolution among the various design disciplines that students engage in during their product design processes. Nine students from three design disciplines (interior design, product design, and graphic design) participated in a workshop providing knowledge about 3D modelling, following which they undertook a re-design task to develop a new 3D form of a detergent bottle. The research data consisted of video recordings and sketches, and the analysis focused on the progress of the design processes and the differences between the groups. The results highlight that the creation of new 3D forms was based on intensive reformulation activities such as setting new problem expressions or modifying existing ones. This kind of re-design task, which presented constraints in terms of developing a new 3D form within the prescribed requirements, served as a good exercise through which to practice co-evolution because it drove the design activities towards a balance of transitions in the problem and solution spaces.

Keywords

co-evolution; collaborative design; problem-solving; product design; sketching; 3D model

Introduction

The main purpose of teaching art and design is to enable students to learn domain-general and domain-specific knowledge as well as apply practical skills related to the art and design field, through which students' enthusiasm, participation, and professional skill can be extended. All design students perform some type of design activity, such as improving a production process, developing functions, planning a project, or creating new forms. Current design education highlights that sketching and digital as well as manual model-making are essential creative design skills. Graduating designers must have a solid understanding of the design process and should be able to apply these skills in a variety of situations.

In the last few decades, as digital design applications have emerged and been absorbed into design practice, they have been recognized as a technology of enormous potential for design (Wu et al., 2012; Ye et al., 2008). Therefore, 3D modelling and rapid prototyping skills have become essential techniques in design education. Various modelling techniques, such as the application of curved surface modelling software (e.g., SolidWorks), direct the vision of design as continuous and integrated processes of ideation and construction. Thus, from the very beginning of a product's appearance development, designing is focused on creating and developing design ideas that are given an initial 3D form. Designers make sketches not just to record an idea but also to help generate it, and sketches are central to the emergence of new thoughts (Menezes & Lawson, 2006). Therefore, ideation involving the visualization of design ideas plays a crucial role and represents a critical aspect of collaborative designing: Proposed and externalized design ideas might provide external stimuli for the emergence of new ideas within a team, which can become objects of shared discussion and evaluation. Nik Ahmad Ariff et al. (2012) described this cognitive process during sketching as an exploration, interpretation, and re-interpretation cycle.

Design researchers have found that problems and solutions co-evolve during the design process (Dorst, 2019; Dorst & Cross, 2001; Lotz et al., 2015; Maher & Tang, 2003; Wiltschnig et al., 2013).Thus, it is important to have a deeper understanding of co-evolution in the context of developing design instruction in higher education. The present study focuses on the analysis of the problem–solution co-evolution of student teams as they design a new 3D form of a detergent bottle. The objective of the study is to develop an in-depth understanding of the approaches to designing a novel product form by students from different design disciplines. The objective is divided into the following research questions:

1. How do the teams differ from each other in their design process?
2. How do the collaborating students carry out the design activities under the task requirements?

Background

The co-evolutionary model of the design process

In design research, there are two main frameworks related to design processes: Simon's (1981) rational problem-solving framework and Schön's (1983) reflection-in-action framework. These two frameworks, referred to as the cognitive and situational approaches, respectively, involve fundamentally different ways of approaching the design process (Visser, 2006). The former approach provides insight into process components (cognitive tasks, constraints, operations, and goals), while the latter addresses issues of the design content and situation (Dorst & Dijkhuis, 1995; see also Visser, 2006). Dorst and Dijkhuis (1995) have argued that the problem-solving approach means looking at design as a search process in which the scope of the steps taken toward a solution is limited by the information processing capacity of the acting subject. According to Goel (1995), who championed Simon's (1981) information (cognitive) processing theory, designing is a search in the unitary problem space, and the design process consists of two types of activity: problem structuring and problem-solving. Problem structuring is the phase in which a problem-solver constructs and reconstructs the problem space and design solutions that emerge gradually as a process of structuring, composing, and decomposing the problem (Goel, 1995).

Schön's (1983) design process model is based on naming, framing, moving, and evaluating activities, and the development of a shared framing is acknowledged as an important factor in collaborative design processes (Dorst & Cross, 2001; Zahedi & Heaton, 2017). During the process of framing, designers also create a particular view of the design problem. Based on these activities, the design problem and potential solutions "co-evolve" over time, with the designer exploring the co-existence of two spaces, a "problem space" and a "solution space," and each space informing one another. The co-evolution view of the design process was originally proposed by Mary Lou Maher (Maher & Poon, 1996; Maher & Tang, 2003) and was later applied by Dorst and Cross (2001) to analyze the industrial design process. While these early papers on co-evolution are still widely referenced, there have been few further studies on the framing and co-evolution of problems and solutions within design projects (e.g., Dorst, 2019; Lotz et al., 2015).

Dorst and Cross (2001) analyzed whether their observations aligned with the problem–solution co-evolution model. They observed that framing design ideas iteratively alternates with the problem setting moving toward the proposed solution state. They found that the designers had developed and refined both the formulation of and solutions to the problem through a constant iteration of the analysis, synthesis, and evaluation between the problem and solution spaces in the same manner as Maher's problem–solution co-evolution model (Maher & Tang, 2003). Furthermore, Dorst and Cross (2001; see also Dorst, 2019) conceptualized a clear link with Schön's (1983) problem framing and proposed that creative insight occurs when a problem–solution pairing is framed. They indicated that this problem–solution framing ability was crucial in creative design disciplines. Within this co-evolution view of design, potential design solutions receive consideration in the context of the requirements defining the problem, and design requirements can be adapted in light of novel solution attempts. In this sense, the design process is the parallel evolution of both the problem and solution space dimensions. Further, Lonchampt et al. (2004) analyzed how the problem and solution spaces co-evolve during collaborative design and how two states can be considered to be shared within the design group. They considered design activity as an elementary process that allows shifting from one situation to another, either the solution definition or the problem expression, and how the shared knowledge about them changed. To improve the evolution between the problem and solution spaces through a focus on and appropriation of activities, it is important to understand that the shifts between these spaces are associated with alternative proposals and the emergence of new criteria (Brissaud et al., 2003). According to Dorst (2019), there is a need for further research, especially in terms of the transitions that represent jumps from the solution space to a new problem definition.

Wiltschnig et al. (2013) examined the validity of a problem–solution co-evolution model of design behavior. Their data consisted of audio and video recordings of meetings held by a five-member design group who worked around various product development stages over five months. They analyzed whether the design episodes were collaborative or individual. Collaborative episodes mean that one member mentions the requirement and other team members propose solutions. Individual episodes mean that both the change in requirements and solutions are proposed by the same individual. They found that the problem–solution co-evolution was most often collaborative in nature. The collaborative episodes involved a variety of directional movements between the problem and solution spaces, and co-evolution activity was dominated by requirements analyses leading to solution attempts. However, they also found numerous instances through which solution attempts sparked requirements analyses, which often resulted in requirement changes.

Sketch-based ideation in teams

In professional design, the importance of sketching and producing various representations has been highlighted (Ferguson, 1992; Goel, 1995; Nik Ahmad Ariff et al., 2012). In collaborative design settings, designers communicate and explicate their ideas visually and verbally in order to reach a shared understanding. Sketching and modelling are recognized as essential in enabling designers to examine and produce design ideas at the very beginning of the design process (e.g., Suwa & Tversky, 1997). Designers examine their designs in several overlapping ways, including through diverse types of sketches, notes, and models of various sorts, and these representations play important roles in different phases of the design process (Ferguson, 1992; Goel, 1995). The skilled use of external representation provides opportunities to define the salient attributes of the design problem and, at the same time, evaluate the appropriateness of the developing solution (Pei et al., 2011).

Professional designers sketch for a reason—the most obvious being to show how a design will look and function (Ferguson, 1992) without the need to construct the actual object. Sketching is an acknowledged thinking tool for designing, but it is also a tool to evaluate and test ideas (Goel, 1995; Schön, 1983). The explorative cycles of sketching, reinterpretation, and evaluation are central to the production of design ideas (Menezes & Lawson, 2006; Nik Ahmad Ariff et al., 2012). Furthermore, Ferguson (1992) distinguished the thinking sketch, the talking sketch, and the prescriptive sketch. Lotz and Sharp (2017) explained that the talking sketch was common in collaborative design because constructive interaction required designers to talk to each other. In their classification, the talking sketch means simultaneous sketching and talking so that either one participant is sketching on behalf of the team or co-sketching where co-designers sketch while talking.

Further, Goel (1995; see also Seitamaa-Hakkarainen & Hakkarainen, 2000) observed two contrasting sketch development strategies. The first, labelled horizontal sketch development, is described as a move from one design idea to another more-or-less different idea. The second, labelled vertical sketch development, is to move from a design idea to a more articulated and detailed version of the same idea. Horizontal sketch development indicates that the designer goes over several design ideas without articulating any of them in depth. This means that the resulting sketches are not clearly connected to each other and that the degree of detail or complexity of these sketches do not increase (see Goel, 1995). Vertical sketch development means that the drawings are closely connected to each other; the sketches being developed become increasingly more detailed and complex and consist of an increasing number of design elements. In what follows, we describe our research setting, participants, method of data collection, and data analysis.

Method

Participants and context of the study

The aim of the study was to analyze how students from three design disciplines would approach the design of a novel product form. We focused on how collaborating students carried out a well-structured design task and how the co-evolution of the design activities occurred. For our exploratory case study, a workshop titled Rapid Modelling Techniques was organized in the summer of 2020 at an art and design college. This was an optional course offered to third-year undergraduate students of the three design disciplines: graphic design, interior design, and product design. It consisted of 21 hours of workshop training over seven weeks, lectures about computer aid design, and acquiring relevant knowledge about design thinking in product design context. Twenty-six third-year design students attended the workshop, which provided them with basic skills in the use of the SolidWorks software. The end part of the workshop was the focus of the data collection for the present study.

The product design students had used SolidWorks earlier, and the interior design students had some previous experience using the other 3D modelling software (3D Max). However, prior to the workshop, the graphic design students had no experience of using 3D software. The goal of the workshop was to fulfil the requirements that all participating students would have some experience of rapid prototyping in order to collaborate during a product design task. Based on this assumption, we were interested in the potential differences between the three design teams as they underwent the same product re-design task.

In this study, we focused on the nine students who volunteered to participate in the experiment. They were assigned to one of three groups based on their design discipline and were asked to undertake a product re-design task. For simplicity, the three groups will be referred to as G-interior, G-product, and G-graphic in order to highlight their specific design fields. Each team's design process was video-recorded, and the screen recordings were used during the rapid prototyping stage. We also collected their resulting sketches, digital models, and design artefacts. The present study concentrates on the problem–solution co-evolution process and 2D sketching as a form of creating. A detailed analysis of the 3D modelling and rapid prototyping will be reported in another study.

Design brief

The experimental situation allowed us to focus exclusively on a well-structured re-design problem-solving situation whose aim was to develop a new form of the product using sections on the form as a starting point (see Figure 1). Besides sketch-based ideation, the students were required to use the curved surface modelling software to construct the form of the detergent bottle. The product belonged to a brand called SMOOT, whose market position was mid-range or even higher than that of similar detergent products. The design brief consisted of a problem definition for initiating the re-design and a specification based on the client's requirements. The group members were required to develop, within constrains, the form of the bottle of a detergent product.

The design brief was formulated to cover some predetermined product requirements. The students were asked to follow the requirements below:

- Expand the capacity by 30% based on the original bottle,
- Develop the form by adding novel and desirable features,
- Keep the 3D model similar to the original form by at least 50%,
- Take account of design rationality when dealing with the form and function.

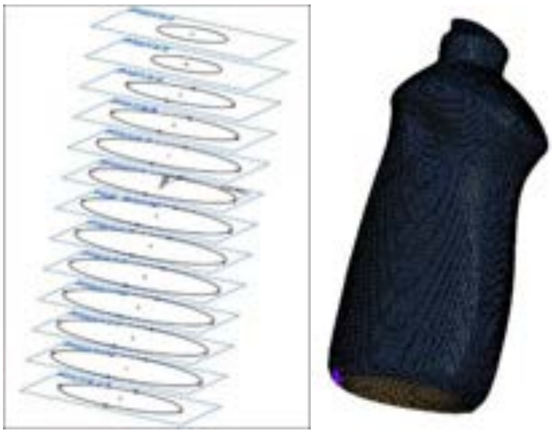


Figure 1. Series of sections adapted to the modelling task and mesh data collected using 3D scanning skills

The duration of the product re-design task was limited to about 2.5 hours, including knowledge seeking, ideation, sketching, and 3D modelling. Each group was required to perform their design activities in succession:

- Defining and framing design problems by talking, writing, and gathering information to explore solutions,
- Ideating by sketching to explore visual features based on the solutions produced,
- Modelling a 3D model with SolidWorks based on the produced 2D sketching.

Data collection and data analysis

The entire design process was video-recorded, and screen recordings were used during the construction of the 3D-models. For the video analysis, we adapted Ash's (2007) approach for tracking design process phases. First, for a macro-level analysis, we segmented the video data into one-minute units and identified the design activities in each unit. Product design activities are generally recognized following the phases of an iterative design process such as problem recognition and analysis, information gathering, idea generation, and evaluation (Goldschmidt & Porter, 2004; Lee & Jin, 2014; Tversky, 2005). Thus, we classified the design activities in the following categories, which were validated in our previous studies (Lahti et al., 2016): 1) analysis constraints, 2) ideation, 3) information seeking, 4) sketching, 5) 3D modelling, and 6) talk about the computer technique. The categories were not mutually exclusive, so the one-minute units could include several activities at the same time, such as ideating and sketching. Based on the categorization, we created flow charts for each group, showing how each design activity proceeded during the session.

In the second stage of the analysis (i.e., micro-level), we focused on the activities of problem–solution co-evolution. This analysis was limited to the time preceding the 3D modelling phase. The focus on the collaborative design process allowed us to observe the problem-solving activity of the participants, especially solution development. Table 1 presents an example of the video recording and transcription of the problem-solving activity. The classification is explained in Table 2. We used the following four categories: 1) proposal, 2) definition, 3) evaluation, and 4) reformulation.

Table 1. Extract from the video-recording in G-interior

Time	Verbalization	Sketching Activities
00:03:28	Z: Um, you should add a little decoration on it. D: Look, there is also (a need) at the bottom.	 Normal camera view from the top angle.  Stylized camera view from tripod camera.

Table 2. Categories and excerpts of the co-evolutionary design statements

Proposal (PD)	Proposing and explaining a new solution (or new elements of a solution).	*...then, is there a little bend? Maybe this half does not need much round...*
Definition (D)	Explaining, interpreting and communicating a proposed solution (or proposed elements of a solution) among design team.	*Right, I think so, um...it is used this shape, then I hope ... There is a bulge we can grasp it using one hand.*
Evaluation (E)	Judging a proposed solution in regard to the problem expressed.	*You give a good idea; I think this can increase the volume of the bottle.*
Reformulation (R)	Setting a new problem expression or modifying the existing one. The first initial problem expression is considered as a particular reformulation.	*...Yeah, have a straight one like that placed in our dormitory.*

Our study relied on descriptive statistics of the encoded data. To compare the differences between the three groups, we compared some of the quantitative differences of the main design activities (time used, frequencies). Since this exploratory study involved three teams, testing the statistical significance of their mean differences would not have been meaningful. First, the time used in the main design activities was represented on a flow chart. Second, for the micro-level analysis, the frequencies of the four co-evolution categories were analyzed. We were interested in the quantity of each category and the variations between the problem-solving activities of the three design teams. We then distinguished not only which activity was more or less involved in the problem-solving phase but also identified how the activities alternated throughout the design process.

Results

A comparison of the design activities

A reading of the brief revealed that the time spent by the groups on the design processes varied between 71 and 111 minutes. The video data were divided into one-minute units related to the various types of activity that we analyzed on the group level. Design activities such as ideation and sketching usually occurred simultaneously, with one participant sketching on behalf of the team while responding to the other team members' suggestions. Also, other members drew sketches in order to improve ideas discussed in the teams. During the early stage of the problem formulation and 2D sketching, the groups worked collaboratively to analyze constraints by proposing, testing, and evaluating design ideas and producing solutions. Next, during the events involving the 3D reconstruction and modelling, the independent work increased, and one member of each group focused on producing the 3D modelling.

Figure 2 presents the timelines of the design activities in each team. G-interior used the least amount of time (71 minutes) to progress through the whole design process and started producing the 3D model after 15 minutes, with G-product doing so after 22 minutes and G-graphic about twenty minutes later (after 40 minutes). Only G-interior had conversations about computer techniques; the SolidWorks program was new to G-interior, and they talked about how to realize the desired effect with certain operations within the software. The discussions about the computer technique indicate that the G-interior team members did not possess the necessary software skills; therefore, they had to discuss how to use certain operations. The timelines in Figure 2 show the design activities during the design sessions. The grey areas at the end of the 3D modelling denote that the video data were changed into ten-minute units.

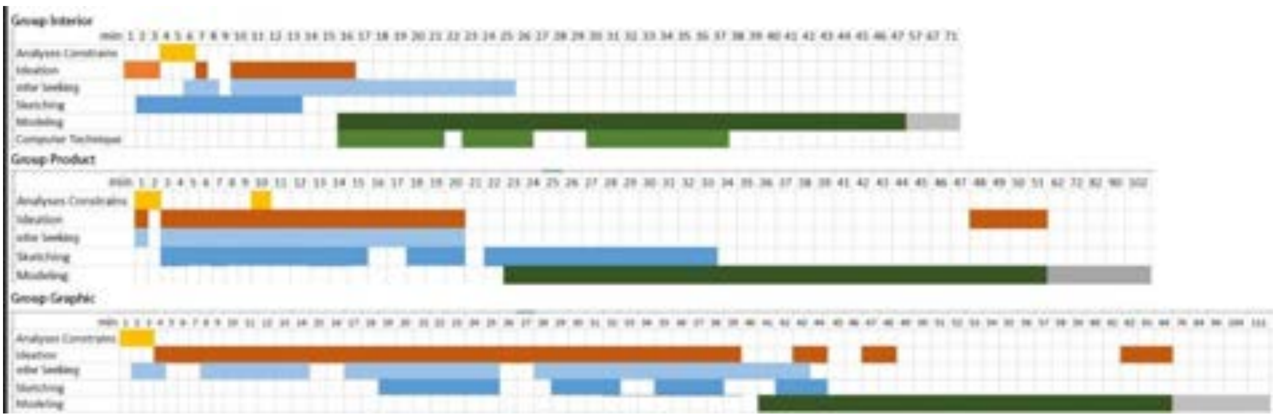


Figure 2. The groups' design activities

The design process began with an analysis of design constraints (G-product and G-graphic), ideating (G-interior, G-product), and information seeking (G-product and G- graphic); however, G-interior and G-product began producing sketches (see Figure 2). The role of information seeking was more like searching sources for inspiration to generate alternatives to sketching. In addition, the information seeking (G-interior) and sketching (G-product and G-graphic) continued even as the teams entered into the process of building the 3D model. Specific to G-interior was that it used up the least amount of time for 3D modelling (56 minutes), ideation (11 minutes), and sketching (12 minutes) compared to the other groups. They quickly developed the idea of a water-related shape and drew various drops form in the bottle sketches (see Figure 3). This corresponds to the idea of vertical sketch development where a proposed design idea is articulated and detailed.

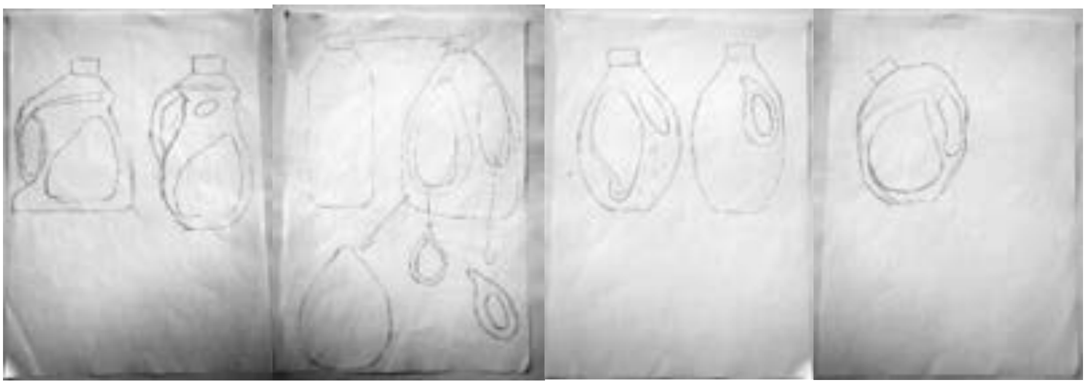


Figure 3. Sketches generated by G-interior

The design process in the G-product team took 102 minutes. Ideation and information seeking proceeded simultaneously (19 minutes), whereas sketching continued into the 3D modelling process. The group members produced a series of 2D sketches, which focused on many details regarding their proposed solutions to the problems or sub-problems (see Figure 4). The sketches were closely connected to each other, developed at increasingly detailed and complex levels, and consisted of an increasing number of design elements (i.e., vertical sketch development). Besides the discussion on creating a detailed form of the bottle, they considered manufacturing-related requirements. One person took responsibility for the sketching while responding to suggestions from others.

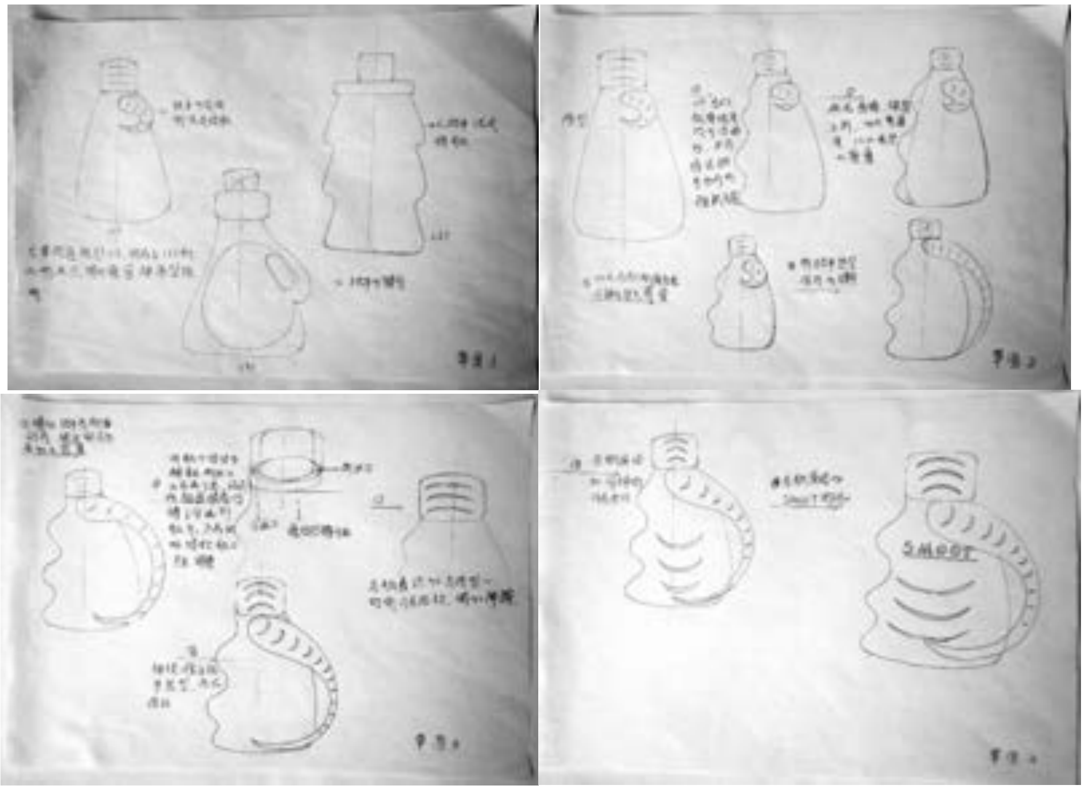


Figure 4. Sketches generated by G-product

In contrast to the other groups, the G-graphic team spent the most time on the design process, with the amount of spent time on the main activities (i.e., ideation and information seeking) doubling that of the G-product team. They also started 2D sketching much later than the other teams. Despite the short period of time spent learning the SolidWorks software, they accomplished a desired 3D model with skills they learned from the workshop. Their sketching process was mainly based on horizontal sketch development because the sketches represented various forms of the bottle that did not increase the complexity of the selected form (see Figure 5).

Figure 5. Sketches generated by G-graphic

A comparison of the problem–solution co-evolution processes

The mixed quantitative and qualitative analyses focused on the co-evolutionary design process of each group. This process involved moving between the problem (design brief and constraints) and solution (proposal of solution attempts) spaces. Accordingly, the co-evolution required a reformulation of the problem state and proposed solutions. As Schön (1983) emphasized, design problems are actively framed or reformulated by designers who act to improve the current situation. Thus, it is presumed that in problem-solving, the reformulation and proposal of a solution are key elements that should be moved into the problem space. Reformulation is setting a new problem or modifying an existing one. Since we were interested in collaborative designing and problem–solution co-evolution while designing a new 3D form, we focused on our detailed analysis in the early stages of the design process, that is, sketching a form of the bottle. As soon as the 3D modelling phase was started, the members of each group turned their working mode from collaborative to individual. It is reasonable to assume that the most competent member in 3D modelling skills undertook the main role during this phase. In what follows, we first provide an overview of each group's problem-solving activities. Second, we deepen the analysis by focusing on how the form developed during the design process and how the groups solved the requirements related to the design brief.

We encoded the verbal problem-solving interactions of the design teams according to the following categories: proposal, definition, evaluation, and reformulation. The time duration of the problem-solving activities and the distribution of the problem-solving statements varied between the design groups: G-product (21 min, f = 143), G-interior (15 min, f = 79), and G-graphic (40 min, f = 114). In other words, G-product was efficient and supplied many problem-solving statements. We calculated the frequency value, which refers to the occurrence of problem-solving activity per minute during the design process. This confirmed the same results: G-product (6.8) had the most intensive problem-solving co-evolution period, followed by G-interior (5.26) and G-graphic (2.85). In addition, we found that the number of statements between the students differed significantly. For example, in G-interior, student A was most active and made most of the statements (45%), whereas student B made 29% and student C 26% of the statements. Student A was most knowledgeable about 3D modelling and the software, so she also knew what forms and aspects needed to be considered. Her statements were important while designing the form for the bottle. Later she also took the main responsibility to make the 3D model with the software.

Figure 6 shows the distribution of four problem-solving categories in each group, the overall distribution of which differed significantly between the teams. The reformulation (R), which involved setting a new problem or modifying the existing one, dominated in all groups. The percentage of the reformulation in G-product was more than half the total (53%) number of problem-solving activities. The corresponding percentage in G-interior was 35% and 39% in G-graphic. However, G-product only recorded a proposal (PD) activity of five percent, which was less than those of G-interior (13%) and G-graphic (15%). These results indicate that reformulation also played an important role in the well-structured re-design task and not only in the ill-defined design tasks. Reformulation drove the teams to explore the problem space more than the solution space.

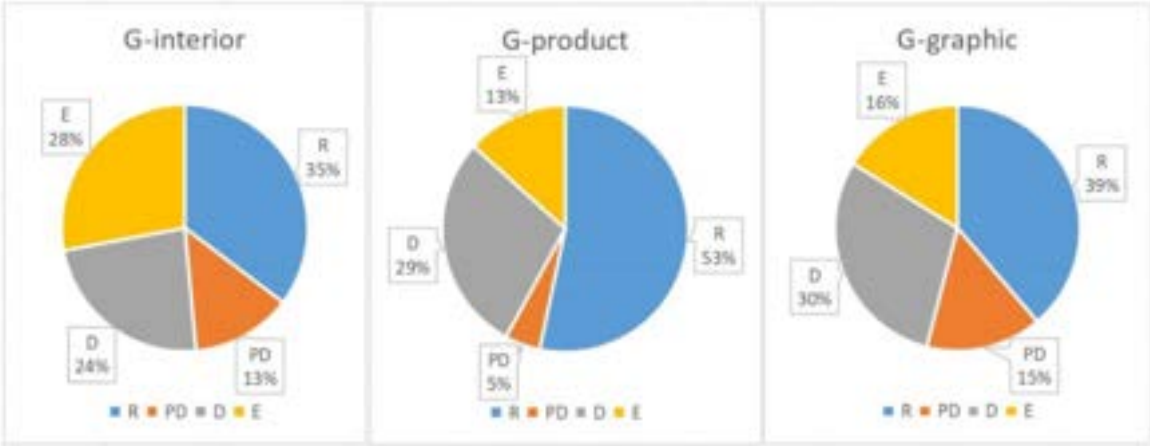


Figure 6. The distribution of problem-solving categories in each group

In the following discussion, we provide a description of each team's co-evolution in developing the 3D form for the detergent bottle and how their solution attempts fit the design requirements provided.

Reformulation as a driver of co-evolution

In relation to the co-evolutionary model of the design process, we found that reformulating the new problem was the driving force in the problem–solution co-evolution process. Table 3 illustrates the transcription of the discussion setting, which comprised the time codes, the students' initials, sketching-related statements, and the categories emerging from the analysis.

Table 3. Extract from a G-product excerpt

Time	Students	Statements	Categories
00:04:18	A	Un, I am thinking if we could change the shape like this one. 	PD
00:04:20	B	Exactly, this is a good idea, yeah.	E
00:04:26	C	Um, I am afraid, do you think a problem this will lead to liquid stacking?	R
00:04:30	B	But we use this shape means to extend the volume, you are right maybe. Um. It was nice I am thinking If we could shape the curve to be flatter and smoother than the original, maybe better.	R
00:04:42	C	You mean decrease the curvature of the curve of shape, then the shape will be changed.	R
00:04:43	B	Correct.	
00:04:50	C	At same time, we need ensure the handle could be hold by a palm when people use.	R
00:04:51	B	um, I think so.	
00:04:55	A	That is to say, lean the curve vertically then the liquid could flow slowly down.	R
00:05:01	B	Yes, no need flatter and smooth too much, but let it much smaller, um.	R

In this episode, G-product focused on a new proposal from student A. Subsequently, an element of the problem was defined by student C, who posed a new problem (*this will lead to liquid stacking*). To solve this, the problem was separately decomposed into two sub-problems (*shaping the curve to be flatter* and *leaning the curve vertically*). However, here, there were no evaluative statements; instead, a putative solution for *shaping the curve to be flatter* was proposed. Following a long discussion, this solution attempt was again shifted toward the problem space with another sub-problem (*leaning the curve vertically*). Similarly, no evaluation ensued; instead, new reformulations were continuously generated by the student team members. It was important that they structured a common ground based on student C's question regarding *liquid stacking*. Subsequently, they continued with the reformulations and set problem expressions to achieve the final form of the bottle. Following a further period of discussion, at 00:11:22, student B first drew a thumbnail sketch to present the resolution of making the bottle flatter and smoother, as shown in Figure 7. During this episode, their activities were fixed on finding solutions to solving the problem of *liquid stacking.* In this sense, G-product focused on reformulating the design problem in functional terms (i.e., specific functions that the form needs to fulfil), which left room for adequate alternative solutions.

Figure 7. Thumbnail sketch to present the resolution

Creating solutions through definition and evaluation

In G-interior, the key idea of the form of the bottle was the shape of the waterdrop. Table 4 illustrates the transcription for the extracts. The episode shows how G-interior used the shape of the waterdrop to improve the feature of the bottle. In this episode, they did not clearly reformulate the problem statement but relied on definition and evaluation activities.

Table 4. Extract from a G-interior excerpt

Time	Students	Statements	Categories
00:03:50	A	Wait a minute, you should sketch it firstly.	
00:03:53	B	Yes, some rough sketches.	
00:03:58	A	Surely, after we confirm at the end then finally use a fine picture. At here, a waterdrop, it is round and big at the bottom, and top is a little sharp. 	D
00:04:01	C	Look, here also need.	D
00:04:02	A	Then, there is a handle. Hmmm, actually it's needed more changes, we can make it like one entire waterdrop. What do you think?	PD
00:04:09	B	Ahh, take care, that's too big... more than 30%.	E
00:04:12	AC	Ahh…	
00:04:14	A	Um, not too bad, the handle could be at here. And at another side create one more waterdrop feature. But there cannot make it sharp, I cannot make it.	D
00:04:15	B	Um.	
00:04:28	C	Do you want one more hole on there?	D
00:04:29	A	No, no, no.	E
00:04:33	ABC	Ahh…	

Their design episode began with a definition generated by student A about discussing the shape of the waterdrop. Student A simultaneously produced some sketches. The discussion proceeded around the topic of how to use the waterdrop shape for the bottle. Then, student A proposed a description of the shape (*we can make it like one entire waterdrop*), which was rejected by student B. Next, student A defined another element (*create one more waterdrop feature*) for use on the other side of the bottle. Consequently, student C pose the following question: *Do you want one more hole on there?* This question required an evaluation about using the waterdrop shape on the other side, but it was rejected by student A.

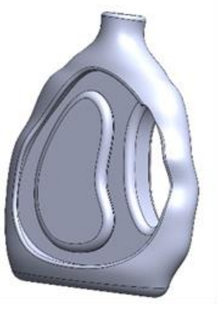
Generating proposals for a satisfactory solution

G-graphic produced more proposals than the other groups. At the same time, they were considering the design constrains from the problem space and did not reformulate the problem state. At the beginning, at 00:00:55, student C proposed adding a handle to the body in response to the requirement regarding expanding the capacity by 30%. They then discussed using the form to solve the problem of expanding capacity. Subsequently, a limitation emerged regarding keeping the model similar to the original form by at least 50%. However, in focusing on the constrains from the problem statements (00:02:37), student C proposed a provisional solution in response: "*Like the original bottle, we only hollow out the body on one side, then we keep on leaving most of the original form*," which garnered support from the members. Relating to adding novel and exquisite features, the members held discussions around suitable novel features for decorating the body of the bottle. At 00:07:45, student C proposed the use of a "*decorative pattern on the body, like that bottle of mineral water*." Therefore, some arguments focused on assessing which patterns were appropriate for such a decoration. Later, at 00:09:05, while considering the constraint of expanding the capacity by 30%, student B proposed another solution to *narrow the underside of the form for similarity with the original form.* Again, at 00:12:04, regarding the decoration idea, student A proposed using a waterdrop shape, and at 00:24:26, student C proposed another alternative that would be "*easy to make its 3D model*." Similar arguments based on aesthetic criteria were proposed in their evaluation and reflection.

Meeting the requirements in the design brief

All groups took responsibility for the product re-design task—they determined the design context and how to proceed with writing, sketching, and modelling. All students attended the workshop to learn the rapid prototyping techniques and later successfully achieved the design solution for the complex design requirements. In the design brief, the students were asked to expand the capacity by 30%, develop a new aesthetic form, and take account of design rationality when dealing with the form and function. Table 5 summarizes the outcomes of the design processes. All final product designs met the requirement of the 30% capacity increase. The students' design thinking involved creative and rational working to evoke design ideas such as the handle of the detergent bottle. However, only the product design students considered the viewpoints of end users during the design process.

Table 5. Summary of the fulfilled requirements

	G-interior	G-product	G-graphic
Expand the capacity by 30%	Through enlarging the size of body to achieve a 30% capacity increase, but they didn't sufficiently consider the aesthetic issues when they designed the bottle.	They sufficiently considered the aesthetics on the shape of the bottle when they formed the shape, then a nice combination was created between the capacity and the aesthetics.	An oval shape was used to create for the bottle's body, also meet the requirement of 30% capacity rise from the design brief.
Develop the form by adding novel features	Adopted the element of waterdrop to create the idea of the bottle's body. The waterdrop shapes were used as three concaves on the surface for creating the body of 3D model.	More novel and detail were considered for 2d sketching and 3D modelling, for some examples, the top cap, the smooth handle, and the logo and curve for decorating.	The body was designed to be of a simple style. They tended to utilize much smooth and bent curve for decoration, such as oval line on the body and used kidney shape creating the handle.
Take account of design rationality when dealing with the form and function	They seemed as using visual elements for their evaluation activity, e.g., *that's too big more than 50% (A), there cannot make it sharp(B).* These statements separately have the meaning on somewhat visual element for their design rational.	Such as the solving problem of *liquid stake up* and *the handle could be hold by a palm* these can be seen as they utilized end user's viewpoints for developing the form.	They always used some similar questions for their evaluation, such as *look at this, it's beautiful, isn't it?* and *Is this beautiful or much complex?* They tended to adopt a judgement confined on 2D visual element for evaluation activities.
The accomplishe d 3D models			

Discussion

The co-evolution perspective has not received significant attention in design education (Lotz et al., 2015). However, it would be beneficial if students were aware of co-evolution processes because the ability to frame problems and solutions through co-evolution is critical to an advanced understanding of design cognition and design metacognition (Ball & Christensen, 2019). Typically, co-evolution has been related to the ill-defined problems, where greater flexibility is to be found in the manipulation of the problem and solution spaces (Dorst, 2019). However, our study showed that the design teams also approached a well-structured re-design task by simultaneously exploring the problem and solution spaces. These detailed descriptions of the dynamics in which new design ideas are generated help practitioners recognize the key aspects of the problem–solution co-evolution process. Furthermore, this kind of re-design task, which presented constraints in terms of developing a new form within prescribed requirements, was a good exercise for practicing reformulation. However, the workshop setting and time limits might have constrained the students' approaches to designing.

In this study, we focused on the early stage of the problem–solution co-evolution process as consisting of specific problem-solving activities along with sketching. According to Self (2017), sketching is a potential driver for increasing solution-focused activity and in facilitating the iteration between problem definition and solution ideation. In accordance with this, we found that ideation and sketching were carried out simultaneously and in collaboration within all groups, even though the time used varied between the teams. Ideation and sketching usually occurred so that either one participant was sketching on behalf of the team while responding to the other team members' ideas in visual form, or other members were also drawing sketches aimed at improving ideas negotiated together. The students turned their attention to specifying their design in detail by constructing talking sketches. Two of the groups (G-interior and G-product) relied on the strategy of vertical sketch development. These groups worked with only a few design ideas, which were further articulated through constructing the prescriptive sketches. Contrary to G-interior's vertical sketching, sketching in G-graphic progressed in a horizontal manner. They produced many design ideas by generating several alternatives for the 3D form of the detergent bottle. A previous study (Seitamaa-Hakkarainen & Hakkarainen, 2000) highlighted that more experienced designers tended to consider only a few design ideas and then focus on developing and articulating them in depth. In this respect, G-graphic indicated novice-like practices by moving quickly from one design idea to another. According to Lotz et al. (2015, p. 45), "if educators want to encourage ideation of multiple solutions they need to teach bridge building between problem and solution spaces, but if they want to encourage the working through of ideas they need to emphasise parallel co-evolution."

The results indicate that G-product had the most intensive problem-solving co-evolution period. The creation of new 3D forms was based on intensive reformulation involving setting new problem expressions or modifying existing ones. Consequently, the students developed the ability to rapidly evaluate the design context and iteratively project promising possibilities. According to Crilly et al. (2009), product designers seek to resolve competing factors of both product form and consumer response such as drawing attention to the product, fostering recognition of the product type, generating attraction or desire, and supporting comprehension of function. Furthermore, the fundamental idea underlying designing is that design problems and solutions are explored in parallel from different stakeholder perspectives, including those of users. However, it should be noted that user-centered design methods, particularly in design practice based on the study of user experience, have been used in the teaching and learning of the product design students but are not extensively adopted in the other design disciplines in China. User-centered design, being the previous domain knowledge, helped the product design students adopt an end-user's perspective. Our results indicate that the other design students focused much more on the visual elements of the form than on user-related aspects such as usability. Despite the differences in the design activities, all three teams succeeded in creating a new 3D form of the detergent bottle that met the problem requirements. To conclude, it is important to improve students' understanding of the form of the product and the functionality of the proposed 3D model, for example, through analyses of usability and user-centered methods.

Conclusion

Developing professional design skills requires students to be able to perform a range of design tasks and learn to recognize various design constraints. Comprehensive co-evolution requires openness to the outside world beyond the original problem space (Dorst, 2019). Design students need to be guided toward questioning their design on different levels so that the design process can become more value-driven and user-centered rather than focusing only on developing the product's appearance. Our research indicated that it was challenging to implement this kind of broader view in the short workshop. However, from the viewpoint of design education, it is important that students practice various kinds of design tasks during their education, including well-structured design tasks that play an important role in scaffolding their design learning. In addition, design projects where students are initiated into the design process and provided models in their efforts to solve open-ended design tasks that include certain external design constraints and that take several weeks to complete play an important role in learning design practices. In design education, these projects have become progressively complicated as studying progresses, preparing students for professional practice, mastering embedded knowledge, tools, and skills, and gaining an embodied understanding of the "professional-way-of being" (Adams et al., 2011). This variation of design tasks requires *reflection-in-action* that characterizes the knowing and practices of skilled performers in design (Schön, 1983).

There is a need for future studies to deepen the analysis of problem-solving co-evolution between different design fields and professional experiences. Further research is also needed to understand 3D modelling and the role of user-centered design. For example, there is research on how bottle designs and rapid prototyping can be used as stimuli to collect users' emotional responses (Lee & Self, 2018). Rapid prototyping techniques are not used only for increasing the capabilities of product design students; they should also be taught in other design disciplines that train students in coherent rational activities in the industry design context.

Acknowledgements

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Design Empathy in Students' Participatory Design Processes

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Abstract
In this exploratory case study, we focus on empathy, an important aspect of contemporary design practices. We aim to explore how design empathy manifested in students' design processes. A three-month participatory design project was created and assigned to students (aged 14–15), with the following brief: 'co-design and make an e-textile product for kindergarteners according to their wishes and needs'. We examined 72 end-user-related design episodes from two student teams (six students in total), analysing students' end-user-related considerations, as well as different signs and dimensions of empathy. Our findings indicate that the students considered, discussed and referred to topics concerning end users during the process. Signs and dimensions of empathy were found in the various end-user-related discussions and empathetic considerations, through which end-user-friendly design products materialised. We conclude that students could practise empathic design by acknowledging end users in multiple concrete and abstract ways and designing and manufacturing meaningful products for end users. This offers new opportunities for engaging students in reflective (digital) design and making, targeting design-literate citizens in the 21st century. However, this novel field requires further studies in educational contexts other than higher education, which currently has the best research coverage.

Keywords
Empathy, design thinking, participatory design, maker education, STEAM, 21st-century skills

Introduction
Over the past few decades, the focus of design has been shifting to more participatory, collaborative and context-driven (i.e., human-centred) approaches (Kouprie & Sleeswijk Visser, 2009; Sanders & Stappers, 2008). Empathy is one of the core attributes of designers in the future design, as it enables connecting with people and communities, and through this, design and generate meaningful design solutions (artefacts, services and experiences) (Tellez & Gonzalez-Tobon, 2019). Dindler and colleagues (2020) argue that participatory design (PD) has a lot to offer in engaging and empowering students in the process of designing, making, and learning with and about new technology and how it affects the world around them (see also DiSalvo & DiSalvo, 2014; Iivari, 2020). In PD, the design is a social and collaborative process among diverse stakeholders, and ideas must be explored in a hands-on way and tried out early in the design process, emphasising human centredness and empathy (Bjögvinsson et al., 2012).

Research with a focus on empathic or human-centred design at primary and secondary education levels is still limited (Klapwijk & Van Doorn, 2015). Earlier studies with such a focus (notably in the Netherlands and England) mainly concentrate on developing and analysing methods to facilitate empathic and human-centred design (see e.g., Demetriou & Nicholl, 2021; Klapwijk & Van Doorn, 2015; Van Mechelen et al., 2018). In the US, Goldman and Kabayadondo (2016) and Noel and Lu Liu (2017) have promoted empathy building through the methods of design thinking, and Clapp et al. (2016) have discussed its relation to community-based maker education.

Empathy in design involves interrelated cognitive processes and affective experiences (Kouprie & Sleeswijk Visser, 2009). We define empathy based on Cotton's (2001, pp. 10) review: '(1) the affective capacity to share in another's feelings, (2) the cognitive ability to understand another's feelings and perspective, and (3) the ability to communicate one's empathic feelings and understandings to another by verbal and/or non-verbal means'. As empathy and empathic formation can be developed (Cotton, 2001; Singer & Lamm, 2009), we explored the possibilities of using and fostering empathy in a PD school project in a Finnish lower secondary school. Relying on the notion that end-user-related discussion can indicate empathy (Van Rijn et al., 2011), we aimed to gain an increased understanding of how design empathy (thereafter, empathy) was manifested in the students' verbal design episodes. In this study, we asked the following research questions: 1. What kinds of design aspects did the students consider during their end-user-related design episodes, and how were they driven by their empathy for the end users? 2. How did design empathy manifest in the students' end-user-related design episodes?

Empathy in Design

Empathic design was originally aimed for designers to understand and make sense of the human experience in order to develop successful products (Koskinen et al., 2003; Leonard & Rayport, 1997). However, over the past few decades, end users have been more actively involved in building possible alternative futures through co-design and PD methods (Tellez & Gonzalez-Tobon, 2019). Although empathy is an essential part of contemporary design, the field lacks a fundamental understanding of what empathy in design is and how it can be achieved (Kouprie & Sleeswijk Visser, 2009).

As noted by Smeenk and colleagues (2019), in the social-psychological literature, empathy is usually divided into cognitive processes and affective experiences and the ability to be attuned to or distinguish between the self and others. Kouprie and Sleeswijk Visser (2009) created the framework for empathy in design, which integrates these factors, and they emphasised the need for a balance between users' ideas and visions, alongside designers' personal insights and experiences. Van Rijn and colleagues (2011) emphasised motivation and willingness as important factors in empathic design. Later, Smeenk and colleagues (2016) stated that acknowledging different perspectives would be valuable in empathic design. Hess and Fila (2016) integrated four dimensions – cognitive processes, affective experiences, self-oriented and other-oriented – into their conceptualisation of empathy. Those dimensions, as well as the empathy factors proposed by Baldner and McGinley (2014), functioned as the basis for Smeenk and colleagues' (2019) framework for evaluating a junior designer's empathic capacity. Smeenk and colleagues' (2019) framework comprises five dimensions that indicate empathy: the other-oriented categories of emotional interest (EI, i.e., cognitively attending and attuning to users' emotions) and sensitivity (SE, i.e., affectively attuning to and being in contact with others), the self-oriented categories of self-awareness (SA, i.e., distinguishing between the representations of one's own actions, perceptions, sensations and emotions, on one hand, and those of users, on the other hand) and personal experience (PE, i.e., connecting to and reflecting on one's own relevant experiences), and the 'mixed perspectives' (MP), which indicate that designers can alternate between other-oriented and self-oriented perspectives. Based on these studies, empathic design appears as a dynamic and relational process.

Methods

Participants and Research Settings

This qualitative case study was organised in a public lower secondary school in Helsinki as part of an elective eighth-grade craft course. The project is part of larger efforts (Growing Mind project funded by the Academy of Finland) to bring design and maker education to Finnish primary and lower secondary schools and develop the Finnish Invention Pedagogy in close research–practice partnership with schools. Ten participants (aged 14–15), who had prior experience in textile crafts but none in PD, co-design methods, e-textiles or collaboration with kindergarteners, were divided into three teams (2 teams with 3 members each, and the third with 4 members). Craft teacher, researcher, two kindergarten teachers and 16 kindergarteners (aged 6–7) also participated in the project. The overall idea for the project was formed in collaboration with the kindergarten teachers. Kindergarten is obligatory in Finland, so all students had experiences of kindergarten daily activities and routines. Thus, it was considered easier for the students to be attuned to the end users' needs by knowing the design context at some level.

The first author (thereafter, researcher), who is also a craft teacher and designer, designed the project's overall structure and planned the design brief and the design tasks. The plans were discussed and revised weekly with the responsible craft teacher, and both facilitated the students' design process collaboratively. The teacher and the researcher already knew each other, so their interaction and collaboration proceeded smoothly, which was conducive to creating the proper classroom atmosphere for creativity, sharing experiences and risk-taking. The students were supported in finding their own paths to contribute to the design process. Since the project was part of formal education, the teacher was responsible for the students, for teaching them and for the assessment, giving her a certain power position. Familiarity with the school allowed the researcher to plan and be present in all sessions with the teacher, which helped obtain the holistic picture of the process.

The design brief for the project was to 'co-design and make an e-textile product for the kindergarteners according to their wishes and needs'. The task emphasised collaboration among the team members; considering other people's ideas, feelings and needs; and thinking creatively about how technology could be used in the designed products. Moreover, the students had to physically leave the school building, visit the kindergarten and take the role of a 'participatory designer' in front of the pre-schoolers. Both the teachers and the kindergarteners were considered the end users. The three-month project was undertaken in the spring of 2019. The class met 12 times in weekly 90-minute sessions; the last three sessions were dedicated to student presentations and the post-questionnaire (Table 1). The teams documented their process in the digital SeeSaw portfolio. For this project, the teacher wanted to mix the groups to prevent some generally unmotivated students from being in the same group.

*Table 1. The design process phases and activities (*not fully recorded; **not recorded).*

Sessions	Design process phases	Activities
1*	Discover & empathise	Writing memories and reflections on post-it notes; drawing empathy maps; filling up the pre-questionnaire
2*	Discover & define	Visiting the kindergarten; observing the space; directly interacting with end users; collecting data on their needs and wishes
3	Define & develop	Forming small groups (ice breaker); asking 'How might we…' questions; ideating in small groups; voting
4	Develop & deliver	Ideating in small groups, making fast mock-ups; end users visiting the students' classroom to watch their presentation and provide feedback; collecting feedback
5	Develop & deliver	Developing and finalising the concepts according to the end-user feedback
6	Manufacture	Manufacturing the products
7*	Manufacture	Open day: parents visiting; manufacturing the products
8	Manufacture	Manufacturing the products
9	Manufacture	Finalising the project and the poster
10*	Deliver & present	Delivering the outcomes; making presentations in front of the end users
11**	Share	Sharing to a wider audience at the University of Helsinki Invention Fair
12**	Reflect	Filling up the post-questionnaire; reflecting on the overall process

The project followed the Double Diamond design model (British Design Council, 2005) and started with empathising. This model was chosen because of its focus on empathy. In Session 1, the students made empathy maps; in Session 2, they visited the kindergarten for need observations and interacted with the end users. Based on those observations, the end users' needs and wishes, and discussions with them, the researcher put together different 'How might we...' questions for Session 3. The students brainstormed solutions to the design challenges and subsequently voted for their favourite concept to work with. Then, concepts were developed, and rapidly constructed mock-ups were presented to the end users in Session 4. These concept designs were developed further, based on the end-user feedback, and the manufacturing phase started in Session 5. Finally, in Session 10, the functional needs-based design products – 'Season Tree' and 'Strength Crow' (Figure 1) – were brought to the enthusiastic kindergarteners. Later, the students and the craft teacher presented the project (Session 11) at the city-centre Invention Fair, organised by the research team from the University of Helsinki.

Figure 1. Season Tree and Strength Crow products designed and manufactured by the students.

Data Collection and Method of Data Analysis

In this study, we focused on analysing the design (including manufacturing) processes of two student teams, according to the students' willingness to participate in the study. Team 1 (Emmi, Sofia and Sara – pseudonyms) designed the Season Tree. Team 2 (Iina, Senja and Rosa) designed a soft toy called the Strength Crow. Research permissions were obtained from all participating students, and versatile data were collected during the project.

The primary data comprised approximately 18 hours of video recordings from classroom Sessions 1 to 9. Go-Pro video cameras were placed on each team's table and were moved around the class when needed. Some sessions were not fully recorded; in Session 1, filling up the pre-questionnaire was left out, and we did not have the research permissions for video recording in the kindergarten visits (in Sessions 2 and 10) and from all parents during the open day (Session 7). Session 11 at the UH fair and Session 12 were not recorded, as the former was a public event for hundreds of people, and in the latter, the students filled up the post-questionnaire and reflected on the process individually. Additionally, we had some technical problems capturing Team 1 members' voices as they actively moved around the classroom (Sessions 6 and 8). Altogether, the video data analysed in this study comprised approximately 10 hours of video recordings.

The secondary data comprised photos of the students' sketches, mock-ups, ideation notes and final design products; the researcher's field notes, research diary and voice memos made after the lessons; the students' pre- and post-questionnaires, and other pedagogical materials, such as PowerPoint slides for the class. These secondary data were utilised to support monitoring the overall process and to confirm our results.

The qualitative data were analysed in several cycles and at several levels, adapting the model proposed by Derry et al. (2010). The first phase comprised writing a rough content log of all video data to obtain an overall picture and reveal the main contents and various activities of the sessions in the design process. Then, we systematically identified all those episodes in which the student teams held discussions related to end users (e.g., the user environment or possible future use of the design). We utilised MAXQDA software for the qualitative data analysis and the identified 72 end-user-related episodes that were transcribed verbatim. Analysing the students' team discussions relating to end users enabled us to reveal the kinds of empathic concerns, experiences and reflections that emerged from the students' interactions in the design process. Based on the 72 end-user-related episode transcripts, we created a process table similar to Ash's (2005) flow chart. To this end, we added versatile basic information (e.g., session, project phase, data collected and assignments) and photos of the students' post-it notes, sketches, mock-ups, notes and design products to better monitor the overall process.

The overall analytical process was accompanied by the writing of memos, which included definitions of categories, preliminary analytical notes and questions raised from the analysis. Whenever the transcripts failed to fully capture a specific moment, we returned to the video data to strengthen our analysis.

To answer the first research question – What kinds of design aspects did the students consider during their end-user-related design episodes, and how were they driven by their empathy for the end users? – we utilised the data and theory-driven analysis (Hsieh & Shannon, 2005) to identify the main design aspects related to different kinds of end-user-related design episodes. In this analysis, we focused on the product-centric and the people-oriented aspects (Table 2). The product-centric aspects comprised discussions about functional features or solutions (how a product functions or what its purpose is, e.g., what it teaches children), technical solutions (how the product can be produced, e.g., which material is suitable or how a certain digital technology functions) and visual and aesthetic features (what the product will look like, e.g., its attractiveness and shape).

Human-oriented aspects comprised self-oriented and other-oriented aspects (based on the model of Hess & Fila, 2016) of end-user-related design episodes. The students' self-oriented experiences and knowledge included their own experiences from kindergarten, experiences of the topic at hand or the kindergarten visit (e.g., previous experiences in craftmaking or what was seen in kindergarten). The other-oriented considerations were derived from the end users or their needs, wishes and feedback (e.g., kindergarteners learning about seasons or end users' preferred colours).

Table 2. Categories and examples of design aspects in end-user-related discussions.

	Categories of design aspects	**Examples of design aspects in end-user-related discussions**
Product-centric	Functional	*'...those snowflakes could be used at least in the beginning of spring...'*
	Technical	*'...somehow (made) of such type of plywood sheet, and then, it will be attached to the wall...'*
	Visual/Aesthetic	*'...it would look more vivid...'*
Human-oriented	Self-oriented	*'My guess is that if those weren't safe, then we wouldn't do this sort of thing, so…'*
	Other-oriented	*'Yep, so that they can read it.'*

To answer the second question – How did design empathy manifest in the students' end-user-related design episodes? – we applied Smeenk and colleagues' (2019) framework. However, we extended its descriptions of categories based on earlier studies (Van Rijn et al., 2011; Smeenk et al., 2016; Hess & Fila, 2016) to better support our analysis (see Figure 2). Hess and Fila's (2016) model lacked designers' own contextual experiences; furthermore, compared with Kouprie and Sleeswijk Visser's (2009) framework, we found that Smeenk and colleagues' framework offered a more detailed analytical lens for our needs, which was easier to operationalise to our data.

Our extended framework comprised four empathy dimensions from Smeenk and colleagues' (2019) framework: PE, SE, EI and SA. During the analysis, we searched for the following signs of empathy (similar to those used by Van Rijn et al., 2011): voiced empathic expression (e.g., 'I think/feel/guess the kindergarteners feel/think/want...'), expressions comparing or relating to one's experience (e.g., 'I remember when I was...'), questioning user needs or making assumptions about user needs, and announcing certain facts or knowledge related to the users (e.g., 'Some kindergarteners can read already.'). All these discussions and expressions were coded with the four dimensions, but these dimensions were not exclusive. As our whole study was organised to emphasise Smeenk and colleagues' (2019) MPs, the latter as considered more of a design strategy rather than its own category during the analysis.

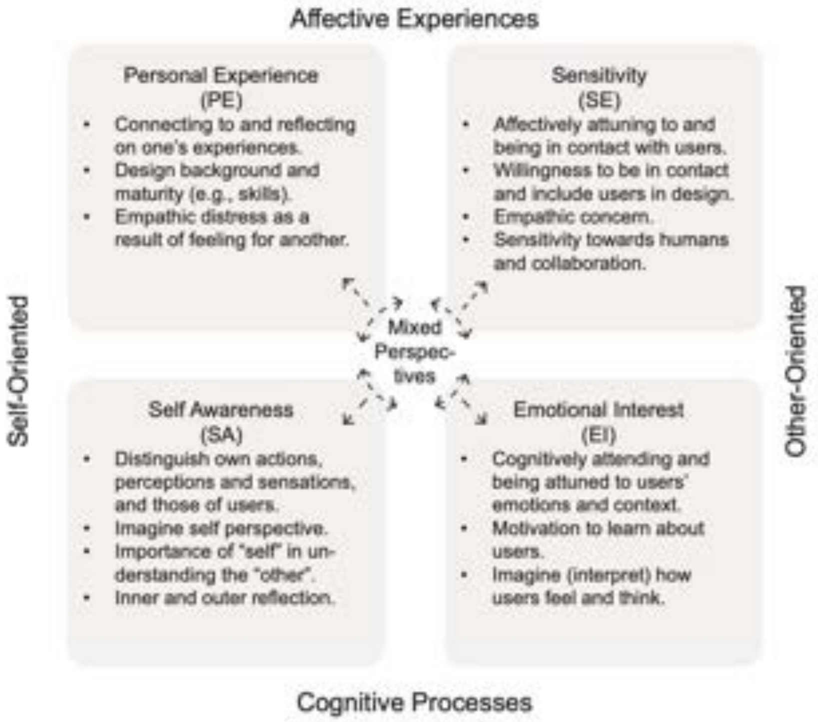

Figure 2. Design empathy framework, extended from the framework of Smeenk et al. (2019).

Findings

In general, both student teams were very active and engaged in the given design project that was quite different from the usual craft studies. We identified a total of 72 end-user-related design episodes with various durations. Team 2 discussed about and referred to the end users, not only in the beginning of the project but throughout the project. From Team 1, we could not verify end-user-related discussions on the manufacturing phase (Sessions 6 and 8), as the students actively moved around the classroom and mostly focused on their individual work. In this section, we start by answering the first research question related to the concrete user-centred design aspect that they considered during the project. Then, we explain our analysis of the more abstract-level empathic dimension.

'What kinds of design aspects did the students consider during their end-user-related design episodes, and how were they driven by their empathy for the end users?

Our analysis revealed that the students considered various product-centric and human-oriented design aspects in 72 end-user-related design episodes. In both teams' processes, the most common end-user-related design episode featured functional and other-oriented aspects. The findings also indicated that other-oriented end-user-related considerations and the students' self-oriented experiences played a role during the design process. Notably, these five design-aspect categories were not exclusive, and most of the time, the students' discussions related to many categories within the same episode.

The functional category included various considerations of the product's purpose or the kinds of intended functions it might perform and how these features could be included in the final design. For example, Team 2 (Strength Crow) pondered whether the crow could play a sound when the noise in the class was too loud, thereby functioning as a noise warning system, or whether the crow's eyes would be blinking LED lights.

> *Rosa: 'And what if the [LED] lights would be the eyes [of the crow]? Or some buttons here?'*
> *Senja: 'Yeah, I was also just thinking that the LEDs could be used there. But I don't know how about the sound; is it [the crow] going to caw somehow?'*
> (Team 2, Session 4, Episode 1)

Team 1 (Season Tree) discussed how children could decorate the tree by themselves and how snowflakes could represent the wintertime and green leaves could symbolise the summertime.

> *Sara: 'Yeah, in principle then, the summer, autumn and spring leaves could be mixed up all over the place. And those snowflakes could be used in the beginning of the spring at least.'*
> (Team 1, Session 5, Episode 6)

The technical considerations related mostly to material choices, for example, whether Velcro should be used to attach the strength cards to the Strength Crow or whether real (wet) branches should be used on the Season Tree. Deliberations about the water resistance of the programmable board, the strength of the material or coding issues were also included in the technical considerations.

> *Senja: 'We had this idea, that, well, last time, [it] came up that they wanted that noise meter, so it would be that circle [programmable board] in its stomach. But now, I [have] started to think where we [should] connect those strength cards then.'*
> *Iina: 'Yeah, but what if they are connected with some Velcro?'*
> *Senja: 'Yeah, if we put it, if there was a Velcro in those wings.'*
> (Team 2, Session 6, Episode 1)

The following excerpt represents the discussion about using LED lights in the Season Tree:

> *Sofia: 'If there was a light inside those leaves, or there in the middle of the flowers...'*
> *Emmi: 'Yeah, I thought also that in the middle of the flowers. But if those flowers are removable, how do you get it [the light] connected to the circuit?'*
> *Sofia: 'What?'*
> *Emmi: 'Well, look, if those flowers are removable, how do you get it [the light] connected to that circuit if you remove them in the middle? Yes, that press fastener, if we get that…'*
> *Sofia: 'That press fastener, and then it [the light] goes on.'*
> (Team 1, Session 5, Episode 9)

The visual and the aesthetic aspects were also actively considered by both teams. These issues included several considerations about the size and the model of the product. For example, Team 1 pondered whether the sketch of the Season Tree looked too scary for the children and how to make the tree visually more attractive with bright colours. The idea was that the different seasons were represented by using different leaves or flowers; thus, the tree's colours, font model and material and leaves were considered important aesthetic features to ensure that the kids would like it.

> *Sara: 'I thought that in autumn, it rains a lot, so I put a rain drop, and then, I don't know if it looks like a maple leaf. But perhaps with these colours, so that they all understand what is being sought by this. I thought that this flower could be some, or these could be yellow and red and some of those really bright colours that come out or so...'*
> (Team 1, Session 5, Episode 12)

Team 2 considered whether capital fonts were easier to read or whether rainbow colours would be well liked. Furthermore, the colour of the LED lights was intended to change according to the different strengths, but LED lights in the eyes of the crow were considered too scary.

> *Iina: 'Those types of that, they will see them.'*
> *Senja: 'And that it looks nice for them.'*
> *Iina: 'Here, we got rainbow colours.'*
> *Rosa: 'Yeah.'*
> *Senja: 'Everyone can be pleased.'*
> (Team 2, Session 8, Episode 1)

The human-oriented aspects were interwoven with product-oriented aspects. The self-oriented category comprised notions where the students brought up or recalled their prior experiences in kindergarten, the kindergarten visit or craftmaking. For example, Team 2 discussed what they had played on the kindergarten field trips. They also referred to the experiences collected during the kindergarten visit.

> *Emmi: 'We did have, we had some kind of rabbit with Arthur [their previous teacher], didn't we?'*
> *Sara: 'No, we didn't, but that was no strength [-based creature].'*
> *Emmi: 'Yep, they didn't have any such features.'*
> *Sara: 'They [kindergarteners] have that bunny, some kind of brown hare, in kindergarten.'*
> (Team 1, Session 3, Episode 4)

They used personal emotions as part of the design as well. Earlier experiences in craftmaking were also in this category, as if they were connected to making for the end users.

> *Sofia: 'Well, I feel that many would get bored with that sound, but…'*
> *Emmi: 'I would lose my nerve.'*
> (Team 1, Session 3, Episode 16)

Nevertheless, we also detected one PE/personal emotion that might have negatively affected the empathic process, as Rosa from Team 2 stated in Session 6, 'I don't want any dark colours; I hate dark colours.'

The other-oriented category comprised notions derived from or concerning the end users or their situations, needs, wishes or feedback. This category represented the clearest end-usercentric considerations during the design process, for example, statements recalling what the end users had expressed earlier. These needs and wishes were especially discussed during the ideation phase, in which the students generated different solutions, such as proposing a 'dressing-up game' to motivate the children to dress up in winter overalls faster before going outdoors, as it is a daily practice in Finnish kindergartens. They also suggested educational ideas about the water-level metre to indicate with a light when the plants in the classroom need more water in order help the children take care of the plants. Later, the student teams considered what kind of feedback they could request from the end users or how the teams could include user wishes in the design of the artefact, as the following examples indicate:

> *Emmi: 'Well, they wanted some branches there, and we thought that it would be quite difficult, so we thought [that] if we would roll up some fabric and then attach them longitudinally to that.'*
> (Team 1, Session 5, Episode 11)
>
> *Senja: 'It is ok, when it can be placed in the stomach like that. They [kindergarteners] told [us] that it would be nice to have the buttons there.'*
> (Team 2, Session 5, Episode 5)
>
> *Senja: 'Rosa, what we... what could those questions [for the end users] be? If the other would be that would they [the kindergarteners] want that it [the crow] would have that kind of colourful eyes that would light up? Then, what could the other question be?'*
> *Rosa: 'Don't know.'*
> *Senja: 'Well, could it be, for example, that where are they [the end users] going to store it, is it somehow attached to that tree, or is it on the table, so do we have to make some... [fastening part]... or something like that?'*
> (Team 2, Session 4, Episode 10)

Both teams' solutions were developed to offer tangible products to support kindergarteners' learning. The main function of the Season Tree was to demonstrate different seasons in a more realistic and motivating way, as the children could change the leaves, flowers and snowflakes by themselves. The Strength Crow was developed for playing and supporting strength-based education and measuring the noise level. During their kindergarten visit, Team 2 noticed that the space was small and noisy, which triggered the idea of utilising the programmable e-textile board for this purpose.

Many design aspects (e.g., safety, appearance and usability) discussed by the students were driven by their empathy for the end users, as illustrated above. For example, Velcro was chosen to be used for both products, as it enables kindergarteners to change the strength cards, leaves and snowflakes easily and safely, supporting more autonomous, tangible and versatile learning opportunities. The use of the products was considered in terms of easy maintenance and sturdy materials so that they would not break in the children's hands. The visibility of the fonts and LED lights, as well as the pleasant sound of the crow, required the students' perspective taking. Furthermore, different features of and solutions for the final products were derived from the end users or their stated needs, wishes and feedback (other-oriented) or from the students' experiences (self-oriented). The findings of this final product analysis are reported separately (Bosch et al., 2021).

'How did design empathy manifest in the students' end-user-related design episodes?

The second research question focused on analysing how design empathy and its different dimensions were manifested in the students' end-user-related design episodes. Notably, when the students discussed the many end-user-related aspects, empathy was present, as we consider end-user-related discussions the result of applying empathy in the process. In the following paragraphs, we present our findings through selected illustrative examples, adapting the chronological design process.

We utilised four categories to analyse the dimensions that indicated empathy: PE, SE, EI and SA. The empathic design process started with the first design phase – empathise – during which the students produced empathy maps by thinking about and recalling what today's kindergarteners feel, make, play, fear, think and dream about, alongside their own experiences of kindergarten eight years ago. This was the starting point for encouraging the students' motivation and receptiveness and triggered their *EI* in the kindergarteners. A cognitive connection with the end users was established, and later, the connection deepened when the students learned about the users and attuned to their situations on several occasions. In the next vignette from Session 3, two students from Team 2 are remembering their kindergarten visit (on Session 2), as they are ideating solutions to the 'How might we...' questions that the researcher has put together according to the user research.

> *Iina: 'What was the idea behind the Strength Crow there [in kindergarten] in the first place?'*
> *Senja: 'Didn't they have to choose a strength each week, so then on Valentine's Day, they had love and friendship?'*
> (Team 2, Session 3, Episode 5)

The session, with an actual visit to the kindergarten, observations of the space and objects, and interaction with the end users, promoted *SE*. The eighth graders were affectively attuned to and in contact with the kindergarteners, who told them about their everyday life and experiences in kindergarten. In the beginning of Session 3, a student from Team 1 remarked, 'Like, it is nice to be with those kindergarteners, or they are cute.' Real contact and interaction with the users at the later stages supported this affective dimension in order to be sensitive to the learning aids and features that really served the end users.

During the defining and developing sessions (3–5), the students brainstormed and generated design concepts and applied empathy by imagining the designer's self in a user's position (SA) and the user's self in a user's position (EI). They utilised empathic capacity by thinking and discussing about what the kindergarteners felt or how they would feel as kindergarteners. This was a sign of *SA*, as it required the students to distinguish between the self and the other and to understand that they, as designers, were serving the other. The students discussed and reflected on the situation in kindergarten and then developed the design concepts accordingly.

The students referred to their previous *PEs* in the kindergarten context, sometimes indirectly by knowing certain practices from kindergarten. An example is shown in the next vignette, when they consider the games that could be played in the kindergarten when it is dark, but they realise that the children are there during the daytime.

> *Emmi: 'To me, [what] comes to mind [is] some kind of… these would be eyes in the dark.'*

Sofia: 'Oh yeah, that would be scary.'
Emmi: 'Yeah, playing some ambush game in the garden. They just don't have any games in the dark.'
Sofia: 'Except if they come in the morning very early... so then.'
(Team 2, Session 3, Episode 17)

Sometimes, they directly refer to their previous *PEs* by stating what they did or enjoyed in kindergarten.

Senja: 'I was just wondering, Iina, you were at the forest kindergarten. What was the best part of those trips to the forest?'
Iina: 'Eating.'
Senja: 'Yeah, in my opinion, eating was always the best. We went on trips to the forest, too.'
Iina: 'Well, so, there were not so [many more] ... and playing in the forest.'
(Team 2, Session 3, Episode 3)

Later in the process, other-oriented EI and engagement were visible, as both teams wanted the ideated solutions to be desirable, usable and relevant to the end users' needs. SE was present, for example, as empathic concern about the children's safety when using the product so that they would not get hurt. In the next vignette, a student from Team 2 confirms that Velcro is a safer choice than pins for kindergarteners to use.

Senja: 'Did you get any other ideas?'
Rosa: 'Well, I got the idea that we could do the base with the Velcro, and every week, one strength [card] could be attached to it.'
Senja: 'Yeah, that's a good idea. Cause with [sharp] pins, they [the kindergarteners] get entangled and prick themselves.'
(Team 2, Session 4, Episode 4)

Concepts were generated based on the students' experiences and knowledge of the (rather familiar) end-user group and context. They conducted the research together with the teacher and the researcher by observing and interacting with the end users. The students synthesised their knowledge from the prior context to meet the desired design brief criteria and evaluated their design concepts with and for the end users. This cognitive and affective mirroring and reflection between the self and the other required the presence of several empathic dimensions in some episodes. Next, we provide two illustrative examples of the episodes involving Team 1, where different dimensions of empathy are intertwined, and different dimensions are visible.

The first example is from Session 3, in which the students ideate solutions for the end users with 'How might we...' questions. In this episode, the students brainstorm about the need to have a livelier season tree in the class, as the previous one was a flat brown cardboard tree. They refer to other-oriented features and cognitively attune to the user context (EI) by thinking about whether real branches survive inside the classroom. However, during the episode, the students also use their relevant experiences (PE) and knowledge of manufacturing and contribute this knowledge as part of the feature that helps the children decorate the tree themselves (EI).

> *Emmi: 'Like, what if there were some different [items] to pin onto it. Some flowers and leaves made of fabric and...'*
> *Sofia: 'Branches could be pinned onto it from outside... If they will stay good.'*
> *Emmi: 'Oh yeah, yeah, get some branches. Like, real branches.'*
> *Sara: 'And then according to the season, in the fall, there could be like dark leaves and then in the summer, some green.'*
> *Emmi: 'Yeah, change them.'*
> *Sara: 'Yep.'*
> *Emmi: 'You know, those could be like Velcro, like fastened on.'*
> *Sara: 'But I don't know how well it would work if they're made of fabric; one would need to make some kind of Velcro surface.'*
> *Emmi: 'Yeah, but one just like that – well, you didn't participate in the planning of the Xmas play – but kind of like stickers that were made for some of the costumes, or those northern light things that were fastened with the same kind of stickers.'*
> *Sara: 'Yeah. Then we could use that or then.'*
> *Emmi: 'Yeah, then they could decorate the tree themselves.'*
> (Team 1, Ideation Session 3, Episode 7)

In Session 4, the students prepared for the presentation and feedback session (Figure 3). During this session, Sara showed empathic concern (SE) when worrying about whether the kindergarteners understood the mock-up version and the idea behind the concept (EI). The other team members were supportive, and together, they imagined how kindergarteners would think (EI). They expressed SA and their inner and outer reflections by considering how their refinements could help the children understand the design concept (SA). When Sara reflected on the birch leaves and suggested a good way to help the kindergarteners understand them, she also recalled her relevant experience (PE) on the topic.

Figure 3. Team 1 preparing for the presentation and feedback session.

In the second example below, all Team 1 members are cognitively attuned to the kindergarteners; they are interested in and motivated to learn about the end users and to ask for feedback (EI). Especially, Emmi expresses affective emotion (SE) related to this end-user connection at the end of the episode. Additionally, she tries to predict what the kindergarteners might want but simultaneously shows awareness (SA) that this might be something different from what she thinks. The following example is from the episode where the students plan the short presentation for the kindergarteners, as they will soon arrive for the feedback session.

> *Emmi: 'By the way, we can show this [points at the mock-up], like here it is. Or I don't know…'*
> *Sara: 'Yeah, can't we show this, too?' [points at the mock-up]*
> *Sofia: 'Yeah.'*
> *Sofia: 'Then, in the end, we can ask if the tree should be larger or if it is a good size. And then...'*
> *Emmi: 'I think that they might even like this one, or then they might want something really big; I don't know.' [places leaves on top of the tree prototype]*
> *[...]*
> *Sofia: 'Should we say that they could use real branches?'*
> *Emmi: 'Dunno. We could ask if they want real ones or something else.'*
> *Sara: 'Yeah, we could ask.'*
> *Emmi: 'Don't know why, but even though they [kindergarteners] are like little, it makes me nervous to go there [and present the design].'*
> (Team 1, preparing for presentation and feedback, Session 4, Episode 10)

EI and engagement in the project and SE towards the end users were also visible when the students tried to develop the concepts and to combine the season tree and the crow according to the end users' wishes and feedback. The students wanted to please the end users, and they were concerned about whether the kindergarteners would like and be able to use the products.

These examples demonstrate how signs of empathy and its different dimensions appear in the design process, and how these are expressed by the students. We found evidence of all four dimensions in all the analysed sessions, so both cognitive–affective and self–other dimensions played a part in the process. The students showed EI in the end users, as it was the most common empathy dimension visible in the data and was coded almost twice as many times as the next visible dimensions – SA and PE. SE played a role but was the least coded dimension. All of the empathic dimensions were entangled, and it was rare to find only one dimension per episode.

Discussion

The findings of this exploratory case study suggest that eighth graders could practise empathic design by acknowledging end users in multiple concrete and abstract ways throughout the process. Signs of empathy are found in various end-user-related discussions and empathic considerations, resulting in end-user-friendly and meaningful materialised design products (see Bosch et al., 2021). The examples of the eighth-graders' end-user-related discussions present different design aspects and features that are concrete and simple in nature.

Direct contact and interaction with real end users are effective in increasing students' motivation and engagement (Smeenk et al., 2019; van Rijn et al., 2011), and many researchers have suggested autobiographical experiences, allowing designers to be sensitive to users (see, e.g., Van Rijn et al., 2011; Smeenk et al., 2016; Hess & Fila, 2016). In the study of Voigt et al. (2019), empathy depends on children's ability to connect with the problem definition at a personal level. We surmise that with adolescents or younger children, direct contact and the students' own previous experiences of the context are crucial for motivational reasons and in making the whole design process more concrete and being able to apply different perspectives in design. Everyone has an experience of kindergarten and its practices, and these constitute the important connector between the students and the end users.

We have identified all four empathy dimensions (EI, SE, SA and PE) in our dataset, but empathy has proven to be challenging to analyse due to its nature. Furthermore, different dimensions are easily intertwined in episodic discussions, suggesting that different perspectives (MPs) are taken during the process. This confirms earlier studies' findings that empathising in design is a dynamic and relational process, including affective experiences and cognitive processes that move across and between the self- and the other orientations (e.g., Smeenk et al., 2019). Nevertheless, this framework has not been previously used to analyse video data of the long-term open-ended design process, so comparison with other studies is difficult. Moreover, earlier studies on empathy in design at the primary and the secondary education levels have mostly used interview, design artefact, questionnaire and/or field-notes data (see e.g., Demetriou & Nicholl, 2021; Kijima et al., 2021; Van Mechelen et al., 2018). We consider our research as offering new perspectives and insights on studying empathy in design in primary-level and secondary-level education, bringing value for researchers in the fields of both the learning sciences and the child–computer interaction, where the various roles of children in PD are discussed repeatedly (see, e.g., Schepers et al., 2019).

The eighth graders' ideated concepts had to be materialised and the products manufactured by the students themselves; thus, during the process, they referred to their previous experiences in sewing or coding. The process reveals that empathy functions together with these non-empathic elements, such as functional or technical considerations. Hess and Fila (2016) report similar findings in their studies. This might have affected the overall design process, as certain manual or digital manufacturing skills or material constraints existed.

Although the design process is a dialogic process between teachers and students, this study has focused on verbal design discussions among the student team members. When we consider the conditions and the factors that enable the empathic considerations and perspective taking, we must emphasise certain design tasks, asking questions and continuous design facilitation by the researcher and the teacher. Both the teacher and the researcher had earlier experience in craft and design education, which supported this facilitation process. We will analyse the pedagogical arrangements and conditions in a separate publication, so here, we have focused only on examining how empathy is manifested in students' design discussions.

The sample size of this small case study is limited but suitable for this kind of pilot project. To increase this study's reliability, we have offered an overall picture of the process implementation and described and justified the data collection methods and analysis as precisely as possible in a single journal article. To alleviate possible concerns about researcher objectivity or possible biases in analysing the data due to familiarity with the context, we have kept detailed field notes and actively used reflective practices. Due to the small size and situated nature of this study, it cannot be generalised, but the results pave the way towards new studies on empathic PD with a larger group of attendees, in different schools and grades.

The students gave their permission for the data collection, but as this project was part of formal education, participation was not voluntary for them. This, and given that the project class was held at 8 AM every Friday and the students were teenagers, could hinder some students' active participation. We noticed that the students felt some time pressure while trying to complete the products. However, a small student–teacher ratio allowed enough time for instruction, which was necessary due to the time limits of the project.

This project's main educational goal is to teach students about the PD process and empathic perspective taking, and its focus is on students' design processes, not on kindergarteners' participation. Furthermore, the end users' preliminary needs or challenges are expressed by the kindergarten teacher. The children's feedback is highly concrete in nature and focuses only on certain very simple features, such as the product size or the colour of the LED lights. In future studies, to follow the PD ideology on user involvement more profoundly, researchers might want to pay attention to even more collaborative and playful methods of gathering insights from children. Nonetheless, this would need much more time than we have had for implementing this project in formal craft education in a Finnish school.

This study's findings broaden the knowledge of how empathy is manifested in lower secondary school students' design and making process. The value of involving end users in this participatory process lies in learning different 21st-century attributes (here, empathy) and in producing design outcomes (here, meaningful products). We suggest that design, maker and STEAM education as an international field could pay more attention to including end users and communities in PD projects using suitable and systematic approaches, offering ways for students to develop empathy, as well as learn (digital) design literacy skills. This could induce an increased level of awareness about people's life circumstances and needs, thereby creating value in both learning and design outcomes.

Accordingly, we need future studies on how these community-based participatory and empathic practices can be implemented in formal education, for example, how teachers design and support PD projects, balance the process with structure and freedom, and assign students certain tasks to feed implicit learning goals (such as different 21st-century skills) into the process. Based on Sultan and colleagues' (2019) review on improving girls' engagement in technology, the social context has to be adapted to girls; here, empathic and community-based design could offer a way to do so (see also, e.g., Holbert, 2016; Kijima et al., 2021).

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Gendered Pathways in Design Education: Findings from a Public University in India

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Abstract
The substantive aims of education include equitable learning, which stands for equitable gender access to preferred learning and choice within. These substantive aims can be furthered by pursuing certified vocational courses that equalize the presence of males and females in the job market through competitive skill sets. Design education in India was imagined as a composite field encompassing both technical studies and social sciences, and it was concentrated in metropolitan cities and technical institutions. It has now slowly spread to newer cities and more disciplinarily diverse institutions. Our research posits that the current unstructured growth of design education leads to a lack of emphasis on substantive outcomes. Rather, there is a focus on education for the sake of acquiring a certified competitive skill. We further analyze the distinction that has emerged between 'industrial' and 'communication' domains within design. This distinction is visible in the twinning of industrial design with engineering and architecture, while communication design is seen closer to fine arts and aesthetics as a stream not requiring technical expertise. This perception has precipitated a trend of gendered pathways in design education. This study used an exploratory approach to analyze five years of admissions data from the design department of a public university in a Tier 2 town in India, followed by semi-structured interviews with students and alumni. We found evidence to support the thesis of gendered pathways, attributed to factors like conventions of society, perceived safety, learning styles, curricular expenditure, and course briefs.

Key Words
design domains, hard and soft design, technical education, design education, gendered domains

Introduction
The last two decades have witnessed a steep growth in the number of design education institutions across big and small cities in India, with the current number estimated at 1000+. Design education in India has been twinned with technical education since its advent in the 1950s. Evidence suggests that design and technology education have been one of the most gendered disciplines in advanced economies (Harding, 1992; White, 1995; Findeli, 2001). Developing economies like India are being seen to follow similar growth trajectories and similar persistence of inequalities (Chu et al., 2015; Parmar and Modi, 2017).

Within design education, industrial design and communication design have emerged as the two dominant disciplinary subsets. This duality has emerged, perpetuating a 'hard' and 'soft' design dichotomy which is visible in the categorization of the two subsets as 'soft' design, encompassing communication design streams like graphic and service design, and 'hard' design, pertaining to industrial streams like product and automobile design (Clegg & Mayfield, 1999; Findeli, 2001). Existing research in the G-20 economies observes that women are under-represented in what they refer to as 'hard' design areas such as product and furniture design and over-represented in 'soft' design areas such as fashion, jewelry, graphic and service design. They identify this polarity as a platitudinous correlation of females with the body and decoration, and males with technology and shaping (Clegg et al., 1999). There is also a distinct difference in the terminology used for learning outcomes in the case of these areas; 'hard' areas use more technical and systemic terms while 'soft' areas use more artistic and user-centered terms.

Our study was conducted in a public university to uncover the gendered pathways in design education in India. We looked at student enrollment data like socio-economic background, discipline choice and placements to determine trends in the design department during the student's four-year academic journey and subsequent career. We support our statistical findings with semi-structured interviews with students and alumni. Our aim is to add to the scarce literature on gendered access and capability witnessed in the design education space in India. This research can help contribute to gender access literature and, in turn, help highlight the observed barriers to equitable design education in India. It is essential to empower students to creatively assess their own potential and map future professional pathways. Herein, student empowerment is defined as 1) having access to preferred design courses, 2) having the choice to pursue the preferred design course and 3) having the technical ability to pursue the course of choice.

Design is a field that has been predominantly seen as a gendered feminine or feminizing domain, but, as our study shows, it is still a male-dominated field due to unaddressed issues of social perception and perpetuated gendered discipline choices that have infiltrated design curricula from technical education streams such as engineering and architecture. In this paper, we also argue that the persistence of divisions, both gendered and otherwise, in design education is not conducive to innovation and the building of open knowledge systems in a nascent discipline by presenting evidence of problematic perceptions in vocational design education in India.

Within the scope of this paper, we have used the term 'design education' to refer to design as a taught discipline, with formal education in design methods, distinct from fine arts, crafts or technical education (Balaram, 2005). We use the term 'design discipline' to refer to the two large disciplinary monoliths within design education, i.e. communication and industrial design. Further, we use the term 'design stream' to refer to a specific sub-discipline within design, such as graphic design or service design. We have used the 'hard' and 'soft' design thesis first proposed by Clegg et al. (1999) to better understand the gender divide existing within the study of the discipline of design in India. We start the paper by reflecting on design education in India. Next, we share the theoretical underpinnings of this research and describe the methods we followed. We end with reflection on some of our findings and the possible implications.

Background

History of Design Education in India

The advent of formal design education is usually attributed to the Bauhaus school in Weimar that defined the philosophy and ethic of industrial age design from 1919 to 1933. Bauhaus was shut down by the Nazi regime, but the faculty and students migrated globally, setting the agenda for design education. Set up after the First World War, Bauhaus idealistically strove to balance industrialization & mass production with artistic vision and individual expression. Even then, the institute was beset by embedded socio-political hierarchies, further exacerbated and explained by the broader crisis in patriarchy after the First World War where the notion and appearance of being strong and masculine were constantly bandied about with the background of European political turmoil (Ray, 2001).

Vocational design education in India was influenced by the pedagogical developments in Europe, thus embedding a complex history of exclusion of females and minorities (Natarajan & Chunawala, 2009). In India, until the '50s, the craft and design tradition largely stayed outside schools, and vocations were determined by castes and lineage. Artisans trained through family apprenticeship in the largely patriarchal communities (Balaram, 2005; 2009). British colonists reinforced the idea of certified knowledge (Vyas, 2006). Post-independence in 1947, an industrial vision led to the Kothari Commission in 1966. It linked education to productivity and gave importance to science education, work experience, and vocational education. The Indian Institutes of Technology (IITs) were set up as part of this imperative. The National Institute of Design (NID) was the first Design institute, set up on the recommendations of Charles and Ray Eames. They amalgamated the strong Indian craft and design legacy with skills needed for contemporary industrializing India (Eames, 1958; Vyas, 2006).

Socially, India has many divisions of region, race, language, caste and gender that are also reflected in higher education access and enrollment across population groups and geographies (Natarajan & Chunawala, 2009; Nath, 2014; MHRD, 2021). Focus on gender and minorities was not an explicit concern in vocational education in a fast-industrializing India until the late 1990's, when issues of gender-equitable education first appeared in the Indian planning space. Even after that, the focus was on access itself rather than gendered pathways within technical disciplines like design that were precipitated by historical structural differences.

Gender in Design Education

The annual All India Survey of Higher Education (AISHE) (MHRD, 2019) has consistently highlighted the disparity in gender enrollment issues in higher education, especially technical disciplines like engineering and architecture. Design is included in these categories. Existing design education research relies on management theory for analyzing the gender divide in discipline choice in males and females (Matlow, 2000). The "hammer problem" postulates on why women do not choose disciplines perceived as 'hard', because of a perception that they lack the skill on account of being a woman. So, the hammer requires strength beyond what a woman is capable of. Reassurance does not assuage the underlying sense of inability (Clegg, 1999a). This stems from the socio-technical construct of competencies. Further, gender relations in technical education have been theorized as 'guest' and 'host' where men are hosts and women are guests. The 'host' position puts constraints on men to be seen to perform, while women's 'guest' status gives them relative freedom, but dominance is mistaken for competence and vice versa (Elkjaer, 1992).

The research that has emerged on the connected issues of gendered preferences in technical design education largely comes from American and European studies (Clegg 1999a, 1999b, 2001; Auf der Mauer et al., 2004; Mayfield, 2009; Sequeira, 2012, Williams et al., 2018). This research area has remained largely undeveloped in India, where the spread of technical design outside the few premier institutions like the IITs and NID is a recent occurrence, coinciding with the spread of design education in India in Tier 2 and 3 cities (Dhaundiyal & Dhaundiyal, 2021). Cities in India are classified as Tier 1, 2, 3 and 4 based on population density (MoHUA, 2021), with Tier 1 being the most densely populated. Within this research, analysis of barriers and opportunities to equity in higher education institutions in populous urban centres in Tier 2 and 3 cities takes centrefold. There is a large presence of higher education institutions across Tier 1 cities, but with growing demand, Tier 2 and Tier 3 cities have an increasing number of institutions as well now (Parmar & Modi, 2017). This extends to design education as well. Thus developing this area of knowledge stands to offer correction and insight into the equitable distribution and development of design education in India, where technical education between genders remains largely and highly skewed in favour of males. Tier 2 and 3 cities with design courses need interventionary policy guidance to maintain gender balance and remove observed 'hard' and 'soft' design bias in established Tier 1 centres such as the IIT's where, even though design departments exist, gender participation remains highly skewed in favour of males (Mansuy & Henderson, 2021). However, research from India in the area of equitable pathways within design studies remains scant, leading to a perpetuation of categories of exclusion.

Creation of Categories of Exclusion

The perpetuation of categories of exclusion within design education has strong historical and structural roots. Learning styles are dependent on experience, observation and one's conceptualization of the world, all of which are influenced and shaped by gender (Chou & Wang, 2000; Brew, 2002) e.g. a strong differentiator is the difference in learning styles of design students in relation to their academic performance and gender (Mainemelis et.al., 2002; Cassidy, 2004; Demirbas & Demirkan, 2007). These differences in learning styles form at a very young age (Sarr-Ceesay, 2000). Studies in both, school education (Chu et.al., 2015) and higher education (Stirling, 2007; Miske et.al., 2010) have found evidence of strong gender influence on learning styles and course outcomes. This has been found true in creative disciplines like design and architecture as well (Kvan & Yunyan, 2005). Gender is also a strong influence in the eventual selection of vocation (March et.al., 2010; Chu et.al., 2015).

Selection of vocation has also been attributed to gender competencies and 'incompetencies'. Various theories have been utilized to justify the possible roots of women's 'incompetency' in technical design areas (Nurhaeni & Kurniawan, 2018). The Human Capital Theory describes how voluntary life choices are made in allocating time and effort to tasks such as work or family. This theory suggests that because persons involved in labour-intensive tasks such as childcare and housework tend to select jobs that are comparatively less demanding. This theory thus predicts that because less effort and time is devoted to the job, there are fewer positive performance outcomes such as pay or promotions (Satterfield et al., 2010). The Sex Discrimination Theory focuses on the idea that men perceive women as a child rearer, and as such, it is appropriate to scale back their work duties and outcomes accordingly. Both approaches of describing the effects of family responsibility on job performance suggest that family responsibility has an adverse effect on work effort, particularly for women. This limits women's opportunities for positive performance outcomes such as merit increases and promotions (Lobel & St. Clair, 1992; Reskin & Bielby, 2005; Marlow et.al., 2009).

Studies have looked at the 'barrier' model that reviews existing and potential barriers to females in technical education and flagged factors like STEM inputs in school, occupational environments, and lack of role models and networks that lead to passively made alternative choices (Mishra et.al., 1999; Siann and Callaghan, 2001; European Commission, 2002; Wonacott, 2002). It was also found that often students themselves are not explicitly aware of gender disparities in access and choice in higher education but identified implicit issues like intimidatory behaviour and gender stereotypes in learning (Thurtle et.al., 1998). Research in gender differences in information technology attitudes, use, and skills among students found the learning gap was narrowed when using IT enabled methods that bypassed the deep-rooted biases ingrained in conventional methods (Blurton, 2001; Stepulevage, 2001). This has been found true in vocational education as well (Nestler and Kailis, 2002).

It has been seen that even though the opportunities for females in technology education have increased, many still choose not to pursue it due to their perception of technology education as a male domain (Zuga, 1999). So merely providing opportunities is not enough without addressing the structural issues that affect choice and decision making. The answer for lower female enrollment in technical design courses, however, cannot be reduced to the above biased theories. Looking at multidisciplinary data is one possible approach to analyzing why the technical design gender bias exists and how it is perpetuated.

Methodology & case study

Our study is based at the (XXX University) which offers specializations in product design and graphic design. The city XXX, where the University is located, is a Tier 2 city with a substantial student population from surrounding Tier 3 and Tier 4 urban and peri-urban centres. XXX has many regulated and unregulated private design colleges. Our primary data was collected at XXX University, a state government university running seven technical education schools, including design. The application rate within the School of Design has been steadily increasing, reflective of increasing interest in design studies across the city and the state. The city and its educational establishment are representative of design education development patterns across many Tier 2 and 3 cities across urbanizing India. While exact data on the number of design colleges and departments in India remains absent, the positioning of the city and its design education institutions does allow for a degree of generalizability in design education patterns.

The four year design programme at XXX University is structured as a common one year long foundation course, followed by three years of specialization in a particular stream. The two streams offered are product design and graphic design, based on the conventional disciplines of industrial design and visual communication in design education. As taught in the university, product design relates more to design of 3D objects and physical form while graphic design relates more to visual communication in both digital and print media. The department has a limited intake of 30 students per year, with entrance through a national aptitude test. The average selection ratio is 1:6. The department is part of a public University with affirmative action based seat reservation as followed by the Government of India for marginalized communities, however, this data was not analyzed as part of this study.

The study analyzed two sets of data. The first set consisted of enrollment data from five years of University admissions, taken from registration forms after removing all identifiers. The sample population included all enrolled students in the design department from 2015-2020 between the ages of 19 and 26, some of whom have now graduated. We analyzed data on gender, city and area of residence, parents' employment status and family income brackets.

The second dataset was derived from semi-structured interviews conducted telephonically on account of the COVID-19 pandemic. Non-purposive sampling techniques were deployed to select students as respondents. We sent a recruitment email to five randomly selected students from each batch, and 12 confirmed participation voluntarily and gave informed consent. The number of respondents was equally divided across communication design and industrial design. There were seven females and five males. Only gender, age and discipline were recorded as identifiers for respondents. The language used was primarily English, with some Hindi words, translated for coding purposes. The telephonic interviews varied between 20-30 minutes, following a semi-structured approach. We audio-recorded the interviews and then coded them using Atlas.ti to identify embedded themes. We grouped the codes inferred using grounded theory to generate meta-codes that helped us identify socio-economic determinants in design education pathways.

The interviews contained both closed and open-ended questions. We asked respondents their reasons for selections of design education, a nascent career choice in India, and finally, their reasons for selection of discipline. Their views on social determinants were also sought through casual questioning. This included questions about significant influences like family members, school teachers, relatives, cultural icons, seniors etc. We attempted to identify both formal as well as informal mechanisms that led to their choices. We looked at information channels they subscribe to through which they were informed. Further, we asked them about their aspirations and expectations and how they were met or if they remain unfulfilled. The interviews took the form of storytelling, where the respondents constructed a biographical narrative of their experiences. We ensured that the questions did not presume gender as problematic or ask leading questions with a confirmation bias.

Findings

From Admissions Data

The study found a marked difference in enrollment amongst students. We found that in five successive intakes of the school only 35% of the students were male and the rest were female. However, when we broke down this data by year we saw that the number of males enrolled in the department has steadily risen (Figure 1). The Gender Enrollment Ratio (GER) of India is 0.88 (MHRD, 2021), in favour of males, but we see higher female enrollment here. However, the five-year trend shows that this may be changing.

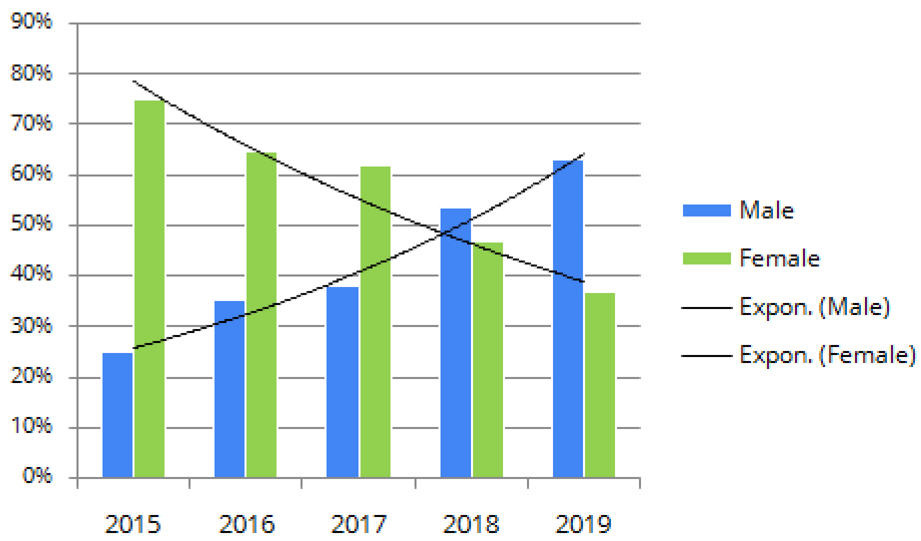

Figure 1: Gender Trend over 5 Years

If we correlate the overall numbers with gender, we find 40% of the male respondents and 54% of the females opted for graphic design. By year data shows that the number of students opting for graphic design has steadily risen (Figure 2). On breaking down the data further, we found more males have been choosing product design while the number of females opting for graphic design has been rising.

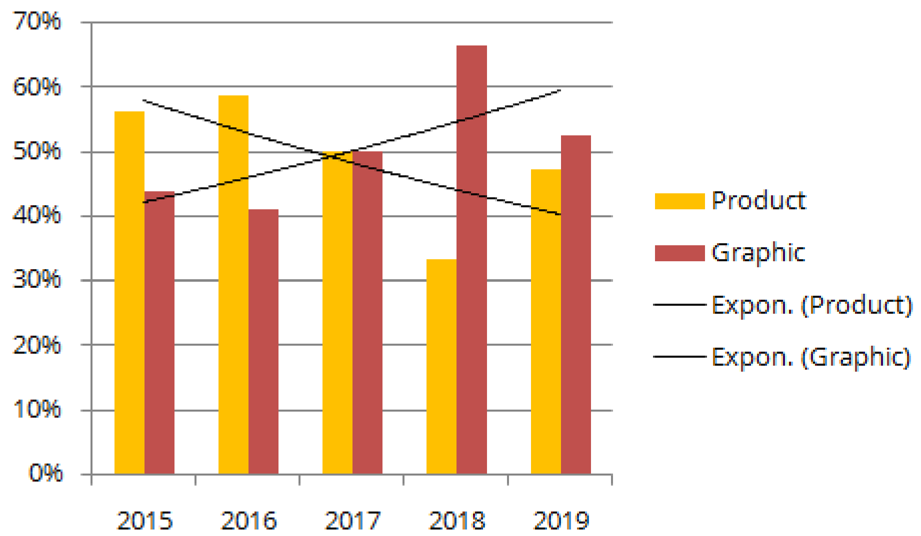

Figure 2: Discipline Trend over 5 Years

In terms of areas where the students came from, we found Tier 2 cities dominated student intakes (Figure 3). The trend in the number of students across different Tier cities was consistent over time, gender and discipline. On closer analysis, adding a gender correlation, we do see more males from Tier 4 towns opt for product design and more females from Tier I cities opt for graphic design. XXX University itself is located in a Tier 2 city, within easy access of large metro cities (Tier 1) as well as smaller towns (Tiers 3 & 4).

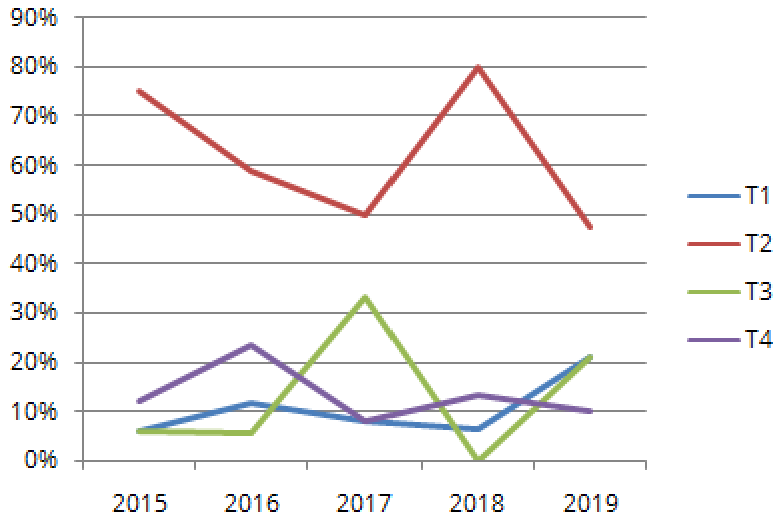

Figure 3: Area Trends over 5 Years

When analyzing family background, we found that mothers of most students were predominantly homemakers, and those employed were generally in salaried service. More male students have working mothers than females. Fathers' employment was consistent for both males and females. Over 60% of the students belonged to lower-middle classes with family income below 10 Lakhs per Annum (USD 14,000), consistent with the profile of government universities in India (MHRD, 2019). There were slightly more females from more affluent backgrounds than males.

If we compared the same indicators across discipline choice in design, we found fewer product design students with working mothers. Fathers' employment status did not vary much, but strikingly, we see a larger number of students from less affluent backgrounds in graphic design, than in product design. 58% students from product design and 80% from graphic design claimed a family income of under 10 Lakhs per Annum. This is cogent with concerns about fees and curricular expenses like workshop and material related costs from the interviews.

From Interviews

Family members emerged as the most influential factor in making education and career-related decisions for both male and female respondents, especially in the case of females where proximity to home was considered quite important. This, to some extent, may explain why more females are opting for graphic design, where they feel the scope of work is limited and restricted to what are seen as 'safe' spaces. The following excerpt illustrates this sentiment:

> *"I can be a graphic designer with one laptop, sitting at home. But product designers always need to run around and collect user information, and make models, and talk to manufacturers. It is so difficult to do that. Some of these places are not even safe for*

girls to be roaming around in. My parents also feel better when I work from home." Female, 25, Graphic Design

Technical competencies and the terminology used for them were found to be a strong influence in student choice. Respondents highlighted the difference in terms used in course briefs and the defined learning outcomes. The two extracts below highlight how course briefs had a prejudicial effect on students.

"I saw spatial and 3D understanding as course objective in foundation geometry and I was like this is not me! I have always been so poor in maths in school and I had to do it in design too, so depressing! And what will graphic designers do with geometry?" Female 21, Graphic Design

"I love shaping things and making new shapes like we did in pottery, but product courses all had so much CAD and technical specification in them, each project needed. So I took Graphic Design. But in the first project only I realized that you can't run from software and specification. Or you can design all you want and the printer will make what he likes." Female 19, Graphic Design

Students relate 'product design' strongly to engineering studies and stronger job prospects. The male respondents seem more swayed by the perception of their choice by others, referencing social stereotypes in their interviews. The excerpts below evidence these propensities.

"We chose a discipline after some 10 months of foundation…we barely knew the 'd' of design, it's too soon to choose! Even my parents knew nothing. So I took what I thought could get me a good job…big companies and factories need product designers. Everyone can do graphics, anyone with Photoshop is a graphic designer. Product is serious. It's like engineering." Male, 22, Product Design

"My senior told me graphics is more visual, you need a very good aesthetic sense. I have been so bad at Art from school times. But maths and science was my strong point and product courses had things like technical studies and complex product design and ergonomics. I would have made a good engineer but I did not qualify for IIT. In product design I got to use engineering without studying it." Male 24, Product Design

Several respondents reported having to convince their families to allow them to study design as an unconventional field. However, the same students also had clear and progressive notions of design education:

"It didn't matter that I took Product. I was always in Graphics studio learning typography and calligraphy and all the super interesting courses they had. I mean if I design a machine interface, don't I need to know which font works better and how the printing will happen? We should have more common courses. Like the space design one. I learnt so much in that; really all design is the same, solving user problems. We just give it names differently. Even fashion, aren't they just meeting a need?" Male, 22, Product Design

Female respondents who opted for product design also reflected a more progressive outlook towards design and society in general, as seen in the excerpt below.

> *"It was fun actually, most of our class was boys and they would act all intelligent and advanced in the workshop but we also learnt quickly. It was so fun to go to hardware stores and ask for a Philips screw! The shopkeepers would look so shocked! Like how does she know?"* Female 22, Product Design

Initial 'access' to design education and then, the ability to make 'choices' regarding future pathways are influenced by various socio-economic markers. The emergent trends within our findings and data analysis point towards the following variables as the influencing factors within accessing design courses: 1) nearby location,2) knowing someone in the field, 3) physical safety,4) long term flexibility, 5) fees and curricular expenses and 6) ability to develop technical competency. These variables emerged as factors for decision making within the respondents. Further, an analysis of the interviews also highlighted the following socio-economic determinants for further choice of courses once enrolled in a design degree: 1) incurred education costs, 2) self-perception of technical expertise, 3) amount of movement required and 4) future success in this field probably populated by able males.

Discussion

The class composition was found to be skewed from the quantitative data (Figure 1) with a larger number of females, though that has been changing over the 5 years of data. Research has highlighted that diversity in class composition in design education brings variety, balance and disparity in ideation and brings different approaches to the table and the benefits of social equality and diversity in engineering and product design education are well-acknowledged (Sterling, 2007; Bjørnstad, 2018). Many of these systematic gender inequalities in design and technical education can be traced back to social perceptions, faculty perceptions and course briefs (Busato, 2000; Brew, 2002; Kvan & Yunyanan, 2005). We see a rise in the number of males in the programme, a majority of whom are opting for product design. We also see a rise in the number of students opting for graphic design (Figure 2), mostly female. This is consistent with Clegg and Mayfield's (1999) findings that gender perceptions influenced discipline choice and evidenced a gendered division. They found a dualism in the over-representation of women in 'soft' design areas and an under-representation in 'hard' design areas. This study found that even though the dominant discourse in design was that of creativity and personal commitment, there was also evidence of gendered competencies.

The majority of the students come from Tier 2 cities, with more females from Tier 1 cities, and more males from Tier 4 cities. More Tier 4 students opted for product design while more Tier 1 students opted for graphic design. This is consistent with previous findings of conventional disciplines still being favoured in smaller cities due to perceptions of higher chances of employability while students in larger Tier 1 towns are found more willing to adopt unconventional career pathways (Nath, 2014; Parmar & Modi, 2017).

Consistent with the profile of government universities in India, most of the students in the programme come from lower-middle class with family income below 10 Lakhs per Annum (USD 14,000) (MHRD, 2019). Design education has high costs associated with materials and tools that are not subsidized by the government in India, unlike textbooks of the more theoretical disciplines. This leads to valid concerns about overall expenditure. This may also be a strong influencing factor in students opting for graphic design which is perceived as a less resource intensive stream by them.

In the interviews, the current students were guarded in their responses at first, with monosyllabic answers, perhaps worried about any reflection on their incumbent status, but the narrative style of questioning helped draw out their responses. Alumni were more forthcoming and reflexive of their positions, perhaps with the benefit of hindsight and a taste of the real world.

Students who opted for product design had some notions about the discipline, which corroborate conventional perceptions of 'hard' disciplines. Males especially seemed focused on future job prospects. In India, engineering has long been seen as a steadfast, dependable vocation, but entrance exams are highly competitive, and final enrollment numbers are low. Some of these students also seem to switch to product design due to its perceived contiguity with engineering studies. 'Hard' disciplines are assumed to necessitate technical expertise and participation in technical activities and spaces that many females find intimidating. The same factor seemed to be driving the males to choose the 'hard' disciplines. We found that the growing number of males enrolled in the department was seen as a validation of design education as a viable career option, especially for males. Respondents felt that it made the discipline seem more 'serious'. Several male respondents voiced they still had to convince their families to join a design course since design is still seen as a less serious profession, seen more as a feminine vocation with echoes of fashion.

We found that perceptions of the dominant disciplinary discourse influence how females and males choose design disciplines and how gender constraints define the design field. There may be no constraint on what females can do, but what they choose to do is discursively constrained by gendered definitions of the technical. Both females and males we interviewed brought up these constraints. Design is a relatively new area of formal education, still in a nascent state, but our study showed that gendered socio-cultural conventions persist in the form of gendered practice and choice mechanisms.

Reflections & further work

The study was aimed at gaining insights into underlying mechanisms influencing student pathways in design. The main contribution our study makes is through deeper insights into the conventional structure and format of design education, and the influence of gender on the pathways students choose. We aimed to uncover the tacit construction of identity and social perceptions in design. Our findings highlight the problematic perceptions and gendering of design domains in design education in India.

The study was limited by the number of respondents and the geographic area, as it was restricted to the students and alumni of one university in a Tier II city of North India and may not be generalizable across all of India. Further work could include expansion of the study to see if similar outcomes are obtained from additional data collection sites. There may also be a difference between public universities that have a limited intake of students per year and private universities that make up for the vast gap in higher education in India with very large intakes. The inclusion of parental data on educational background and perceptions will further enrich the findings. Adjustment of access and perceptions can create opportunities for disciplinary choices, which has the potential to affect diversity within disciplines and gender balance within the skilled workforce and open unfettered pathways for the creation of knowledge and innovation. We see our research contributing towards developing the literature for addressing gender equity and access within design education in India. The outcomes can also be used in course restructuring for developing technical competencies. For example, exposure to CAD, spatial thinking, and 3D form perception could be included in foundational learning rather than being limited to certain streams. Many statistical studies exist but more qualitative research is needed to understand the gendered pathways in design education better. Research across geographies and diverse institutions (like public-private, technical-general) is needed to help understand the larger picture better.

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Landing your first job in Creative Technologies: Soft skills as Core skills

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Abstract

Recent university graduates face an ever-changing professional landscape where it can be challenging to find jobs that lead to successful careers. This is particularly the case for emergent professions such as Creative Technologies, given the changing nature of technology and the value as well as the challenges of working across traditional disciplines. This paper presents a research project that seeks to help fresh creative technologists get better work opportunities in a changing landscape. Students, alumni, and industry experts were interviewed to identify current perceptions and practices, opportunities and challenges, and to generate insights that inform the design of future solutions. Three themes were identified from these interviews: unexplored existing opportunities, a demand for employability skills, and the need for better student-industry interactions. The first refers to opportunities that may already be available but lack sufficient recognition or need more visibility. The second points to the need of an ongoing dialogue between academia and industry to identify the changing landscape of skills in demand. The third highlights the need for creative collaborations across sectors and actors to increase the interaction between students and potential employers. The insights from this study inform the aspects that need to be addressed to design solutions that help Creative Technologies graduates start their careers in the right directions. The research raises new questions about why and how universities in the future can engage stakeholders to make the most of existing untapped opportunities and restructure processes to align with changing demands in industry.

Keywords

Creative Technologies, Employability, Research through Design

Introduction and Background

The influence of digital technologies is increasing as evidenced by terms such as the ‘Fourth Industrial Revolution’ (Schwab, 2017). This calls for technologists with advanced creative and transdisciplinary skillsets. The field of ‘Creative Technologies’ (Creative Tech) aims to prepare graduates who integrate practices and knowledge from various disciplines ranging from Computer Science, Design, Engineering, Entrepreneurship, and Fine Arts (Connor, 2016). This makes Creative Tech professionals prepared to go beyond traditional roles (Connor & Sosa, 2018; Giri, 2002) with the intention to generate new ideas and concepts and implement them into working solutions by bringing together a diverse set of skills across a range of technologies. In the short term, however, recent Creative Tech graduates can find it challenging to find career opportunities inside and beyond the creative industries where they can apply and continue to hone these transversal skills (Hearn et al., 2014; De Freitas and Almendra, 2021).

This study seeks to inform a design-led project to support the employability of recent graduates of Creative Technologies in Aotearoa New Zealand. The research originates from an identified need to better prepare work-ready graduates and connect them to industry, and an awareness of the challenges and limitations of conventional responses to enhance employability (Cranmer, 2006; Trevelyan, 2019). Graduate profiles of university programs in Creative Tech are typically oriented towards creative and critical uses of technology (Connor & Sosa, 2018). The Creative Tech skillset includes advanced technical skills across hardware and software platforms, collaborative teamwork capacities across specialties, creative prototyping, and a user-centred ethos to designing new technologies (Russel et al., 2008; Giri, 2002). The focus of this research is on the experiences of Creative Technologies students and graduates as they are a growing student body who remain under-represented in research to date.

The economic and cultural value of the creative industries is of strategic importance in countries like New Zealand and Australia where they are estimated to contribute nearly one-tenth of the Gross Domestic Product (GDP) and is one of the highest-growing sectors (Flew, 2019). In recent times, public policies have been implemented to strengthen the creative industries in New Zealand including the $60 million Cultural Sector Innovation Fund, the $70 million Creative Arts Recovery and Employment (CARE) Fund, and the $23 million Screen Production Recovery Fund. The skillset of Creative Technologies graduates is of strategic value for the sector in New Zealand as evidenced by the latest (2019) Long Term Skill Shortage List compiled by NZ Immigration[1] which includes occupations such as Multimedia Specialist, Film Animator, Web and Software Developer, and qualifications in demand such as Bachelor of Creative Software, Bachelor of Animation, and Bachelor of Digital Technologies. The fact that tertiary education providers in New Zealand have offered these occupations for the last ten years yet they are included in the skill shortages speaks of opportunities to better understand and address employability issues in fields like Creative Tech.

This research builds upon the existing literature on employability (Cranmer, 2006; Bui et al. 2019), future of work (Schwab, 2017; Gratton 2010), the gig economy (Healy et al., 2017). These areas inform the project's goal to examine how different stakeholders look at employability in this area, and how the nature of this type of work is changing in the local industries.

This research project aims to examine the existing challenges faced by students and recent graduates from the field of Creative Technologies to find appropriate entry-level jobs. The intent is to suggest pathways that will equip them with better career opportunities. The study informs a wider project that applies the methodology of 'Research through Design' (RtD) (Markussen, 2017) oriented towards creative action. The study frames the research question as a tentative design brief for this project asking:

> *"What do we need to know to better support recent graduates in Creative Technologies to find job opportunities that lead them to successful careers?"*

RtD methods link the problem-solving purposes of design practice with the knowledge-creation purposes of design research (Markussen, 2017). RtD leads to a systematic inquiry that takes

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[1] Essential Skills, Ministry of Business, Innovation & Employment: https://skillshortages.immigration.govt.nz/

advantage of the unique insights gained through the design practice in an attempt to provide a better understanding of complex and future-oriented issues (Godin & Zahedi, 2014). RtD is generally defined as a kind of research relevant for design or as a kind of research for design that produces original knowledge (Findeli et al., 2008). Relevant RtD methods include project-grounded research (Grocott & Sosa, 2018), constructive design research (Koskinen et al., 2011), and practice-based (Koskinen et al., 2011; Candy, 2006). These research methods share an emphasis on the creative process being a "way of investigating what a potential future might be" (Zimmerman et al., 2010, p. 312).

There are three primary perspectives on employability. The first is at a macro/national workforce level (Almeida, 2007; Berntson et al., 2006; Lane et al., 2000) related to government policy or national-level skills agendas, or at an industry level (de Grip et al., 2004). The second is about employability in the field of human resource management related to the ability of individuals to get and retain jobs (Baruch, 2001; Forrier & Sels, 2003). The third is related to the universities being able to provide the graduates with skills that employers need (Mason et al., 2003). The work presented here can be placed at the centre of these areas on employability to understand the employability needs from industry, the career aspirations from graduates, and the education approaches from universities.

Design of the Study

This research stems from identifying a need to create better work opportunities for graduates of the Bachelor of Creative Technologies (BCT) program at Auckland University of Technology in Aotearoa New Zealand. The objective for this project derived from the research question is framed as:

> *To create evidence-based strategies to better support recent graduates in Creative Technologies find job opportunities that lead them to successful careers, and which specifically:*
>
> *1) Expose students to industry through opportunities for internships and employability*
>
> *2) Provide industry with early-career staff that have transdisciplinary skills and mindsets*

A research project was undertaken to examine the views, perspectives and experiences of those closely involved with the BCT program and the local Creative Tech industries to generate insights to design a strategy to support employability in this area. Due to its exploratory nature, the project was designed applying an inductive research strategy and adopted qualitative methods to help us identify the issues shaping the experiences of stakeholders. Due to the role of this research project to inform practice, a RtD approach was chosen making it action-oriented and aimed at designing creative solutions (Markussen, 2017). The data collected to inform a design response hinge on how stakeholders perceive work opportunities for Creative Tech graduates. To collect the data, we designed and conducted semi-structured interviews (guiding questions are included in the Appendix). A purposeful sampling strategy was selected to lead to a maximal variation approach for an in-depth exploration to inform creative design practice (Sanders and Stappers, 2012). The open-ended questions allowed the interviewees to elaborate their views without being constrained in terms of what the researchers may anticipate being the issues at play. To guide the process, an interview guide was formulated to assess and determine the set of questions (Mason 2004, Rubin & Rubin 2005).

A pilot study was conducted to inform the design of the interviews. This was conducted to understand the perception of participants of the research objectives and instruments, and to understand if these were the appropriate approach and participants for this research. Four pilot interviews were held with students and graduates. These allowed us to better understand the psyche of the target participants and expand the inclusion criteria to invite stakeholders. These consultations helped structure the design of the interviews and bring down their length to about 30 minutes. The strategy was to make general queries to understand how a range of stakeholders look at the research problem. The interviewer was an active listener to allow them to speak freely about their experiences and perspectives. The pilot interviews confirmed the value of including final year students and recent alumni, and they highlighted the need to also include industry experts who have hired and led projects with Creative Technologies graduates. The final interview protocol was set up and approval obtained from the university ethics committee. The interviewees were asked about their views on the core skills for a Creative Tech graduate, and the kind of companies that are a better fit for these skillsets. They were asked about how networking with professionals can be increased and how members of the industry could be better informed about their skillsets. The industry experts were additionally inquired about what profiles they would hire these graduates for. The interview questions were designed to give a sense of direction to the discussions and allowed participants to speak at length on the topics. With permission from each participant, the interviews were audio recorded and transcribed. The questions were kept open-ended and interviewees invited to elaborate their answers and include examples for clarity.

For the selection of students, a poster was displayed on their learning spaces. A brief about the research was shared with participants who contacted the researcher. A social media post also covered the aspects of the research and how it would be beneficial for everyone in the Creative Tech community, and it was used to reach out to alumni. The industry experts were defined as active professionals who have hired Creative Tech graduates and have led Creative Tech teams in industry or local government. We reached out to them through personal contacts and from the interviewees' suggestions. Participants who were a student of or worked with any of the researchers were excluded from the research process. Participant information sheets and consent forms were used in the recruitment protocol.

Participants expressed high interest and enthusiasm for the project. During the interviews they spoke openly and expressed their views, experiences, and perspectives. Interviews varied from 20 to 40 minutes and were held at the university premises. A total of eight participants were interviewed, three identified as male and five as female. Four were industry experts including the CEO of a digital agency, a technical and recruitment head, and a local council member in charge of Creative Tech projects. Among the student and alumni were an entrepreneur who had recently started their own venture and another with five years of experience as freelancer. All had experience as interns at small or large companies working in Creative Tech projects. We adopted an approach to saturation as considered relevant in Research-through-Design methodology, namely based on their sufficiency to form valuable design insights, rather than on data, theoretical, or inductive criteria as customary in social studies (Aguinis & Solarino, 2019; Saunders et al., 2018). In other words, saturation was assessed to the extent that it produced actionable insights to formulate a design solution (Caplan 2018, p. 351).

After each interview, the first author conducted reflective journaling to associate closely with the data. For analysis of the data, thematic analysis was used. Terry et al., (2017) approach of a six-phase analytic process of thematic analysis was used to analyze the data. Familiarization with the data was followed by creating codes; a preliminary set was prepared by the first author and discussed in iterative sessions among the three authors.

Results

These discussions between members of the research team helped draw and refine the initial codes into groups and identify the underlying meanings and differences between groups. While reviewing the grouped codes, multiples ideas started materializing, which would later take shape into more cohesive themes. Some of the major early groupings were about what they think the university needs to do (both from the students' and industry experts' perspective), what industry experts expect from a Creative Tech graduate, and the existing gap between these expectations and the graduate profile of the program.

Additional insights emerged on the existing student-industry engagement practices, what to do about them, and what is needed to better inform industry professionals about the skillset of Creative Tech graduates. These ideas were iteratively combined, divided, and connected to merge into three final themes discussed in the next section, namely:

Theme 1 – Unexplored existing opportunities

Theme 2 – Upskilling the Graduate's 'Employability Skills'

Theme 3 – Strengthening Student-industry interaction platforms

These themes are discussed with an emphasis on how they inform a RtD project. Based on the epistemological nature of this study, these results are presented following transparency criteria for conceptual replication rather than exact or empirical replication (Aguinis & Solarino, 2019). In other words, we expect these results to be consistent in future studies that address the same research question but may use different procedures.

Theme 1 – Unexplored existing opportunities

The first important theme to emerge from the interviews is about opportunities that are already available in this area but are not adequately or sufficiently recognized. This finding draws attention at what already exists, provides evidence of its value, and suggests ways to make the best of it.

Firstly, the interviews suggest that several graduates have been employed in roles that are more specialized or mono-disciplinary, rather than transdisciplinary. This option for Creative Tech graduates to specialise in a narrower and more traditional field is confirmed by the job title that many of them use to identify with in their LinkedIn profiles, including those of our participants: Interactive Art Installation Designer, Digital Designer, Software Developer, Interactive Video, and Game Developer. This is also consistent with the job advertisements commonly found at present in New Zealand employment marketplaces (such as seek.co.nz) using the keyword "creative technologies": UX UI Designer, Data Engineer, Front-End Web Developer, Digital Campaign Manager, and IT Tutor. Some of these positions are associated to more traditional Design, Art, or Engineering programmes rather than a transdisciplinary area like Creative Technologies. To quote a recent graduate who had further pursued postgraduate studies and then gone on to start their own firm:

> *"In terms of the BCT graduates I do see a lot of people gravitating towards sort of single disciplinary jobs".* (Abel, recent graduate, entrepreneur)

Interviewees expressed that the reasons for this *gravitation* towards more traditional roles included that students who initially choose Creative Technologies, identified with more specific areas of interest as they completed their studies. Another reason was that the job market offers a limited number of entry-level positions that require a transdisciplinary skillset, so Creative Tech graduates may have to compromise and apply for the more traditional jobs available. Time and money pressures right after graduation seemed to have been a contributing factor as well in such cases. They stated that while some graduates were happy at the prospect of having landed a job, others can find these traditional roles unsatisfactory. A view shared among interviewees was that in the long run, working at such jobs can be underwhelming and unsatisfactory. When inquiring about whether Creative Tech graduates felt their transdisciplinary skills were not completely utilised at most existing work opportunities, Samantha, a BCT student, expressed their disappointment that not all of their skills were being used. To quote them:

> *"If I am going for a certain role I would still be very disappointed in myself because I have spent so much time and effort doing this and that and when I move out of it, I will get a job where I am only doing this. So, all those other efforts that I put into it for my course I paid for, I would be disappointed. Yes, and I don't want to go out looking for a job that has this one position.".* (Samantha, BCT student)

A second aspect related to unexplored existing opportunities is regarding the type of companies a Creative Tech graduate aspires to join. The recent graduates interviewed expressed their preferences to work at start-ups and smaller sized companies as they perceive this would help them hone their transdisciplinary skills. As a participant put it:

> *"Yeah, smaller companies and start-ups are by merit of being smaller and having, spreading the workload across a smaller group of people, have more need for sort of transdisciplinary skills of at least mindsets. I feel like bigger companies are much more, like if you intern for a bigger company, they are like you are doing this role, this is what like, there are so many pieces in play, they can't have, like it's harder to have people who are free floaters".* (Aaron, recent graduate).

Aaron expressed feeling similar to other recent graduates who felt that working at a start-up is more advantageous because they look for people who can fit into multiple roles and positions. This seems to lead to the inference that people working in smaller companies are more likely to have a transdisciplinary mindset. Additionally, they felt that large companies have very set processes and defined roles, which were less suitable for a Creative Tech graduate. This view was not shared by the industry experts interviewed. They did not consider that size of the company was a key factor for where the Creative Tech graduates should look for work opportunities. In contrast, they consider the biggest factor to be to work at a place where they can be mentored by an expert. One interviewee said:

> *"I think companies that are mid to well established with a good art director or senior design team available for guidance and mentoring".* (Susan, industry expert)

This insight coming from industry experience points toward companies in the creative technologies domain that have the bandwidth and expertise to provide students and fresh graduates with a level of mentoring that helps them nurture their skillset. Based on their size alone, small start-ups seem less likely to afford such mentorship opportunities. This insight would seem to require a change of outlook by Creative Tech graduates. Instead of aspiring to work predominately at start-ups or small companies they would access career advantages by working at companies where they can learn from seasoned experts.

A third aspect of the existing work opportunities that could be re-examined are internships. Currently, the BCT programme offers students varied opportunities, including internships, to give a leg up into the environment where they will work in the future. Internships help students learn professional work skills and network with people, which could go a long way in deciding how successful they are in their career. However, when discussing internships, a seasoned professional mentioned that the current model of internships in Universities may need to be re-evaluated:

> *"But I just wonder if the model of internship is outdated. And maybe that needs to be relooked at".* (Heather, industry expert)

The participants suggested that the model of internships, including those at place in the BCT, deserves more attention in future studies with the perspective that alternative models might work better for transdisciplinary students in the creative industries. One of the interviewees used the term 'project-based internships', where students ought to be associated with the internship for the length of the project and not be time bound as most current internships are. A "project-based internship" would take a person through the entire lifecycle of a project, thus simulating better the actual work conditions in the industry and it would be a better simulation of freelance work.

A fourth aspect of existing opportunities is exposure to an entrepreneurial environment, which most interviewees considered to be important. They expressed that the BCT learning experience already motivates students to think entrepreneurially, but more needs to be done to enable students to act upon their entrepreneurial intentions. As one interviewee commented:

> *"I think, when I first started the whole kind of idea around BCT, and what we were doing was the fact that we were building up for jobs that were not created and that a lot of the reason why we needed a kind of entrepreneurial streak is because the things that we wanted to do hadn't been made yet or they hadn't been offered as a job, or there wasn't a company that hadn't started that yet".* (Adele, recent graduate)

A graduate with experience as an entrepreneur, reflected that an external push was what helped him venture out and taught him the rigours of starting up their company. Interviewees suggest that entrepreneurship remains an unexplored opportunity for the BCT graduates and, by providing the right environments and platforms, it could lead to the inception of more start-ups in this area.

Participants felt that students could be more active in terms of reaching out to people to find the right work opportunities. Some also felt that companies could do more to make opportunities visible, but the prerogative was on the students and recent graduates. A BCT student though had a different perspective on this. She felt that industry wasn't very aware and confident about Creative Technologies and the transdisciplinary skillsets of these graduates, and therefore there weren't many jobs advertised matching their skillsets. As she stated:

> *"Creative tech is very new, you search up anywhere, there's barely any jobs out there. So, a lot of times people don't know, so they don't highlight in the job prescription what a candidate should have or not".* (Samantha, student)

It was argued that while transdisciplinarity is the forte for these students, they often end up in mono-disciplinary and more traditional roles. Reasons offered included own insecurities and a lack of non-traditional roles being offered by industry. Having exposure to multiple disciplines gives them the edge to also work exclusively in one of these disciplines if required and thus be employable in more traditional roles, although that is not perceived as a space where they use their full potential as Creative Tech graduates. Another aspect is that they might have an interest in a single domain and are utilizing the BCT platform to holistically understand how things work together. This would appear to be a manifestation of the multiple elective courses available and self-directed project briefs the BCT program provides to help students choose their own path. While working and growing in a uni-disciplinary role would build on only one skill, it would still allow these graduates to be in a better position than others if they need to pivot to other disciplines at a later stage in their careers.

In conclusion, start-ups are perceived by the students to offer roles with which they associate better due to their own entrepreneurial outlook. This is also because start-ups and smaller companies use digital technologies in more disruptive ways according to the interviewees. While this provides them with the opportunity to be at the fore of path breaking changes in technology, a lack of mentoring and learning at such venues might impact them negatively. Larger companies would afford them instead better support for growth and mentorship. Novel internship models that suit non-traditional transdisciplinary roles could also be explored, and the university could identify and promote ways for students to develop their entrepreneurial intentions.

Theme 2 – Upskilling the Graduate's 'Employability Skills'

While multiple industry experts expressed the view that the BCT graduates are highly skilled at Creative Technologies, they felt there is a need to upskill them to make them more employable. Industry participants identified collaborative, problem-solving, and professional work skills as the main areas of improvement for students to have an effective transition to the work environment. Professional work skills included communication skills, basic work etiquette, and networking skills. The industry experts expressed an expectation for a level of professionalism from the Creative Tech graduates who work with them. A recent graduate, recalling their internship experience acknowledged that industry placement helps in developing these skills:

> *"You start to learn skills that BCT can't offer. Just probably because they don't have enough time to teach us that. So, it's good to have. Professional skills, getting to ask questions to a professional one on one is extremely helpful, just kind of building those, kind of connections through that".* (Adele, recent graduate)

Being better communicators not only makes students more valuable for the company where they work, but also gives them a better start in finding more opportunities due to their improved ability to communicate their ideas and skillsets. An industry expert articulated:

> *"A really important skill I recommend people would have is how to communicate ideas. I have an idea, or I have an application or something like that, how can I communicate that's things effectiveness, how can I communicate that idea of that thing effectively with background information and reference and everything. So basically, being able to communicate ideas effectively at the very least".* (Jack, industry expert)

Basic work etiquette such as punctuality, email writing ethics, understanding how to address clients, track work and perform as a team member, were identified as the main professional skills that would help graduates stand out. An industry expert lamented the lack of these skills in some graduates who have had joined them and had created some embarrassing situations at work.

> *"I think it's a little bit of the soft skills. Someone who, I kind of class communication skills under professionalism, and basic professionalism as in showing up on time, giving fair warning if they are unable to come, being able to dress appropriately …, like what you want to wear, for example when we have an event or something and we are going to a meeting with a client we don't want to see like ripped shorts and bright red socks up to the knees sort of thing. I am giving that as a live example of something that's happened."* (Kate, industry expert)

The general perception among interviewees was that 'networking skills' would enhance the job-hunting effectiveness for students. The industry experts felt that the better the students get at networking, the more opportunities would open up for them. Another industry expert suggested that the students and graduates be more proactive in locating networking opportunities and to be prepared to introduce themselves, show their work, and connect with the relevant community.

Collaborative capacities and problem-solving skills were also deemed as strategic skills that the graduates should excel at. While these appear to be skills students tend to pick up during their years at university, the data from our participants suggests that more emphasis needs to be placed in developing these skills in students. When an expert was inquired what skills, they look for in fresh graduates this is how they defined "core skills":

> *"Core skills - I think that the biggest one is the ability to collaborate, which is from what I have seen in terms of design graduates across multiple disciplines is that this particular degree teaches, like its collaborative, its colab, like it teaches collaborative work more than anything else, so that's the one main thing is understanding, I would like purposely bring in a BCT grad for collaborative purposes".* (Heather, industry expert)

While it would appear that some BCT graduates excel in technical areas, there seems to be a need for some upskilling to be better at collaborative skills, problem solving skills, and to make them more desirable professionally. Notably, the way interviewees refer to these skills as "core" rather than "soft" helps to reframe conversations and initiatives to prepare Creative Tech students.

Theme 3 – Strengthening student-industry interaction platforms

The third important theme from the interview data was a result of participants stressing on the need for improving existing and creating new platforms for student-industry interactions. These include improving aspects of existing events and processes, as well as creating new venues and systems for students and industry personnel to interact. All participants see the university as playing a major role to address these needs. Interviewees agreed that the BCT program produces skilled graduates, and many of them further described these graduates as being better prepared than the average in the industry. Moreover, some interviewees reflected on the perceived advantages that BCT graduates bring to industry:

> *"When I worked with AUT grads that we had, they were miles ahead of what anybody else could do. Like there's not much of that happening in NZ, so I think that's actually the problem more than anything and I would be really sad for BCT students, if AUT thought that they had to change what BCT was, to conform to the industry*." (Heather, industry expert)

The first aspect the data analysis propounds is about changes to how the existing student-industry interactions are handled, with a focus to strengthen existing relations and establish new ones. One industry expert when inquired about what could be done at the university's end to create stronger student-industry relationships, mentioned the idea of creating 'industry allies'. These would be people who work with the university and their networks to promote more of such talented creative technologists.

Secondly, the university's engagement program with smaller to medium-sized companies is seen as needing strengthening. When inquired if the university should reach out to such companies, a recent graduate who had seen this closely, said it was difficult:

> *"Yeah, like the smaller sort of start-ups or sort of not start-ups but just beyond that, coz I know it can be quite daunting to engage AUT".* (Abel, recent graduate, entrepreneur)

The third aspect towards building the university's engagement with industry is to improve student-industry interactions by trialling improved internships models that monitor students' progress and learning. Talking about the importance of monitoring internships, one industry expert suggested that unmonitored internships could affect the student's wellbeing and/or be a waste of time. Another industry expert spoke about students not taking internships seriously, which affects the industry professionals' perspectives towards inviting students in future, and their relations with such educational organizations. Developing new internship models would help create long-term relations with industry while strengthening existing relations with companies.

The fourth aspect towards building the university's engagement with industry to improve student-industry interactions would be to assess the current events organised at the university. The current showcase is an annual two-hour event held after the end of the semester in November. Students from all years put up their work in the studio space for Creative Technologies. Industry experts interviewed expressed a high level of interest in the content of the annual show. At the same time, they mentioned that certain aspects could be refined, like the duration, location, and presentation to improve its impact. Recent graduates also spoke about the constraints in time and space at the current student showcase which leads to the students losing a lot of 'punch' in their work.

Apart from the showcase, interviewees suggested that organizing events incorporating interactive elements like panel discussions or hackathons, with students leading some of them would help build platforms for student-industry interactions. An interesting aspect here is that such events were organised at the university earlier but were discontinued, potentially due to a lack of feedback from industry and other stakeholders about the value of such events. Another industry expert commented that seeing students involved in the organisation of events helped them to look out for students they might consider hiring as well. As Kate stated:

> *"I am a big believer in events doing a lot of good to showcase how good students could be, especially because usually the most competitive students are the ones who are there. I think that in a sense the interactive events, events where people are working together in groups to create projects like game jams, hackathons things like that. You can see the work and you can see the processes and the problems and problem solving. That to me has always been more, like I have wanted to hire people from seeing that".* (Kate, industry expert)

Lastly, interviewees suggested the need for a central repository that would display information about everything related to the creative technologies industry. This would be about events happening around Auckland where they could participate and showcase their work, available or upcoming work opportunities, developments happening and the latest trends in the industry, among other things. An industry representative also mentioned that they are quite often unsure of the quality of the interns they get and have to go by the word of mouth of their references in academia and a platform that helped them assess the skills of the students would be desirable. The interviewees generally all agreed on the strategic importance of growing a more comprehensive student-industry interaction environment.

A Design Response: An Employability Agency for Creative Technologies

The study presented here informs a Research-through-Design project that aims to produce an evidence-based and design-led strategy to support graduates in the Creative Technologies fields. The evidence produced in this study was analysed by the research team over multiple sessions applying the first "bridging strategy" of deriving design ideas from data as defined in generative design research (Sanders & Stappers 2012, p. 204). This process led to the initial synthesis of a type of "Employability Agency for Creative Tech" to support recent graduates in this area find job opportunities by practising and honing their core skills. While the insights produced by our study inform the design of such agency, this is only presented here as a strategy, rather than a detailed solution, which will be covered in future work. The design of such agency is undergoing a process of development. The feedback from participants and other stakeholder would help us validate and/or refine the final proposals for an Employability Agency such as the one tentatively sketched here.

Although we had initially considered a solution being driven by and for students, the study helped us discern a more complex picture where roles, responsibilities, and tasks go beyond the capacities and field of action of students. Rather than an agency being *student-led*, the views and ideas from interviewees suggest a comprehensive strategy led by multiple actors in a variety of contexts to prepare students locate, apply, and get jobs where they can demonstrate their preparedness for Creative Tech careers. Industry experts also expressed their preference for more specific student involvement in the running of university-industry events. They identified situations where students can demonstrate their skills and dispositions as part of a larger picture of university-industry partnerships. In addition, all the interviewees felt that having students drive a comprehensive solutions such as an agency would be too taxing on them.

A second general insight from our study highlighted the need for systemic initiatives, and the importance of assessing their short and long-term impacts. The work required to connect students and recent graduates with adequate employment opportunities could be distributed among existing entities inside and outside the university. Some interviewees further pointed to the need for a dedicated team that coordinates and documents a range of ongoing and future activities to garner best results. Periodic monitoring of these initiatives by establishing a feedback system to reassess their effectiveness were deemed as essential to build inter-institutional knowledge.

The third general insight points toward synchronizing employment and entrepreneurial activities with the academic calendar for increased efficacy. This is primarily because students have their schedules aligned to the university calendar. Therefore, the planning around this work should be based on an annual academic plan with a semester-wise focus. Additionally, since the current annual showcase is held at the end of the second semester, the agency would do best to work around the existing timeline.

Actionable insights related to Theme 1

The interview data revealed several ongoing opportunities that could be more explicitly acknowledged, explored, and utilized. This theme asks for focused initiatives to identify such opportunities and measure their value. It also guides future employability strategies to aid students and recent graduates make informed decisions about pursuing them. The employability agency needs to work explicitly to identify such opportunities.

Based on this theme, the agency would first go about identifying specific companies and qualify the availability of opportunities there. Simultaneously it would interact with students and recent graduates and inform them about the value addition mentorship would bring in and about the long-term benefits of landing in transdisciplinary roles as against mono-disciplinary roles. It would highlight to the students the pros and cons of working at start-ups or larger companies. It would also guide the students on how to make the best of mono-disciplinary roles and the importance of realising the value addition they would undergo in transdisciplinary roles and discuss strategies about how to morph those positions they might land into, into positions with Creative Tech-relevant responsibilities.

Another aspect for the agency would be to explore internships primarily, but not confined to being ‘Project-based’ and work with the BCT leadership at the university to explore and evaluate them. The Agency would also work with them to bridge entrepreneurial thinking to entrepreneurial action by both identifying more university-industry partnerships and seeking internal changes within the program that would bring about this.

Actionable insights related to Theme 2
Akin all university graduates in general, an overall improvement is required to improve the professional skills of Creative Tech graduates. The reframing of so-called soft skills as being “core skills” for practitioners in this area stands out. An action plan around this would require tweaking the curricular and extra-curricular orientations of the BCT programme to incorporate such content in better integrated ways with the more technical content of the curriculum. The plan could involve learning outcomes aligned to develop these skills not as separated from the so-called hard skills as happens in most other undergraduate programmes. The plan could also attempt to get students involved in participating and running events where the integration of all core skills is put into practice in ways that are ascertained by industry representatives.

Based on this, the agency would need to devise and implement an assessment strategy of the core skills and their integration for industry to provide feedback and for students to improve upon and address. The agency could work closely with representatives from the university and with the BCT Leadership to develop a process that would help the graduates in identifying strengths and weaknesses in their core skills. Students could then be directed towards self-directed improvement activities, or work with the programme leadership to develop a schedule of activities to strengthen core skills identified. Personality development trainers could be contacted to develop a program structured specifically for the creative tech graduates. The direct participation of students in planning and running some of these events would be valued by prospective employers.

Actionable insights related to Theme 3
The theme focuses on the need for an improved student-industry interaction. The agency needs to work closely with the university, students, graduates and industry experts. Aspects that need work include the university’s engagement program with smaller to medium sized companies, the need to finding and creating new ‘allies’ in the industry, the current annual showcase, introducing new events fostering high student-industry interaction and creating a central repository to act as an information centre both for the students and the industry. For this the agency would need to incorporate changes in existing processes and events.

Based on this theme, the agency could go out and identify and meet champions of creative technologies and nurture strong relations with them. The agency would reach out to these allies in future to develop stronger industry relations. It would also identify and work with smaller to medium sized companies and seek relevant employability and internship opportunities at these organizations. The agency would also work with the BCT leadership to inquire if a restructuring of the annual showcase could be a possibility, and if such an opportunity arises, work on the duration, content and audience. The Agency could also work with them to revive high student-industry interaction events like hackathons, meet-ups and panel discussions, some led by students. These events are highly recommended by interviewees and were held at the university but have since been discontinued, probably due to a lack of effective feedback from the industry. It would also work to create a central repository which would collectively over time, try to accommodate all the information about events, companies and other relevant opportunities for students. The central repository would also, over time, try and accommodate specific student related information, including their strength in different domains, details of their current and previous projects and the kind of projects they would be interested to be a part of in future, and possibly recommendations and feedbacks about them from their peers and professors. This would help the agency over time to work with industry and students to connect them.

Discussion

This research grew out of a perception that transdisciplinary Creative Tech graduates were landing up with work opportunities that were not to their satisfaction or which did not utilise their skillsets completely. The inclusion of occupations such as Multimedia Specialist, Web and Software Developer, Animation, and Digital Technologies in the list of skill shortages defined by the government speaks of opportunities to better understand and address employability issues in fields like Creative Tech. This motivated a design-oriented project into understanding and tackling the employability issues in this area. A study to inform a RtD project was undertaken to create a design response to explore the issues and ideas to improve the situation in future. The study consisted of interviews with stakeholders and the interview data helped to inductively identify actionable insights to synthesise a tentative strategy for a future "Employability Agency for Creative Technologies".

The topic of this research elicited unexpectedly high interest from a range of stakeholders who play a range of roles and have different agendas and priorities. The topic also highlighted the sense of urgency and anxiety that students and recent graduates have in terms of finding the right work opportunities. Arguably the main result of this study was related to the lack of awareness about existing initiatives and opportunities that go unaddressed, or whose value is not sufficiently appreciated. Beyond the student showcase, in the past more interactive events were organised by the BCT including hackathons and meet-ups. Their dissipation could be explained by a lack of understanding of the value they carry for students and graduates. It is therefore highly pertinent for the creative technologies school and the university in general to be taking feedback from industry and other involved stakeholders.

This study also brought forth the idea about how certain ongoing initiatives such as internships, entrepreneurship and the university's engagement policies with companies could be relooked at to make them more relevant for all involved. It is important for the university to refine existing platforms to enhance their relevance over time. Further research to inform this would be an interesting area to explore.

While this study examined the employability of students and recent graduates of one program at a particular university, this research fits into a more general space. The development of employability as an agenda to be included in the graduate academic program is an area of existing research (Harvey, 2000). What fuels research in this space is the perception of students and recent graduates about them being industry ready (typically informed by an inadequately collected feedback from industry about what exactly the industry needs) and the argued gap between the capabilities of the graduate and the competency levels expected in industry (Almi et al., 2011).

The limitations of this study include a small sample size and a lack of validation of the design, both primarily an effect of the advent of the pandemic, Covid-19. Since saturation in this study was assessed to the extent that it produced actionable insights to formulate a design solution (Caplan 2018, p. 351), the number of participants does not majorly impact the study. The testing of the design response with the participants would have produced strong validation of the study undertaken. The design response formulated from the results of this study diverges sufficiently from conventional approaches to employability training (Cranmer, 2006), including curriculum reform and formal assessment (Trevelyan, 2019). However, it remains to be developed in detail with the inputs from stakeholders and its feasibility and effectiveness assessed, which remains for future work.

The next phase of the study will take into consideration factors related to resources required to implement the strategy generated here. Future work will reach out to a larger audience by capturing quantitative data using a short survey which could possibly yield further issues to explore. According to the initial design of the study, additional interviews would have helped increase and refine the themes identified and could have helped elaborate the design solution in more detail. Despite these shortcomings, the study informs future work. The ideas towards an employability agency derived from this work could be examined in the larger context for related undergraduate programmes in the university and could also inform wider university-industry partnerships as well as entrepreneurial programmes. The project seeks new partnerships with other tertiary institutions in the region that offer courses related to Creative Technologies. We also plan to incorporate to our study a view derived from “teaching-learning ecologies” in the workplace (Bailey and Barley, 2010) given the current state of the Creative Technologies profession in Aotearoa New Zealand. The Covid-19 pandemic has had a profound effect on the work culture, with people having to work alone in isolation from their homes. This would certainly have affected creative technologists especially with the nature of their roles being transdisciplinary. This aspect could also be explored. We also plan to explore how core skills are valued in a post-pandemic work environment and if there is a perceived need among graduates for a type of skills beyond those identified here.

Lastly, given the increasing uptake of online and remote learning modes due to the Covid-19 pandemic, future disruptions in this area are to be expected. With increases in remote work and the automation of creative tasks, the study presented here could be valuable to continuously inform employability initiatives. Insights from our research demonstrates the value for universities to work closely with external stakeholders to make the most of untapped opportunities and restructure processes to align with changing demands in industry and society.

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Appendix 1

Interview Topic Guide

1. What are the core skills people look in a "Bachelor of Creative Technologies" (BCT) graduate?
2. What kind of companies are a better fit for the skill sets (focusing on the transdisciplinary skills) of a BCT graduate? (start-ups or larger well established companies)
3. What are the entry level roles BCT grads join into generally? Are these to the satisfaction of the graduates? What are your views on this?
4. What do you think the creative technologies industry is doing that is beneficial for the BCT graduates joining into the industry?
5. What are the advantages and disadvantages of internships or any other work opportunities during the study period?
6. What do you think could be ways to get more internships / work opportunities – Specific to the Creative Technologies domain?
7. What could be the advantages and disadvantages of Work-integrated-Learning for a BCT graduate?
8. How could members of the industry be better educated about the transdisciplinary skillsets of the BCT graduates?
9. How could networking with industry people working in the creative technologies domain be increased?
10. Would an event (like the current annual Showcase at AUT or other events that happen across Auckland, elsewhere) be a better exposure for the students to showcase their expertise and network with industry representatives?
11. How would you plan/shape organize such an event? Let's say you were the creative director for planning and organising such an event, that would..
    a. Help students showcase their prowess at what they do to the industry representatives in general.
    b. Help create networking opportunities for people working in creative technologies domain, students and university representatives and professors.
    c. Would such an event only be a "showcase" of what the students can make or will it be competitive.
    d. What would be the duration of such an event? A couple of hours or a whole day, or even longer ?
12. What could be other ways to increase industry exposure for the BCT graduates?
13. What profiles would you hire a BCT grad for?

An Exploration of the cognitive processes of design teams to inform design education and practice

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Abstract

While design is associated with novelty and creativity, few studies have explored the cognitive processes employed during team interactions. Design practice is collaborative where designers work in multidisciplinary teams. Along with the cognitive skills involved in designing, designers also need skills to work in teams, share information, and negotiate decisions. The aim of this study is to understand the cognitive processes used by design teams during the early phases of product design. This study uses case studies and applies content analysis to examine the conversations of design teams during the problem definition, ideation, and concept development phases of the design process. Creativity has been described in terms of sudden bursts of ideas described as creative leaps and is associated with creative thinking. The findings in this study shows that while creative thinking is essential to creative teams, other cognitive modes such as knowledge processing, critical thinking, and metacognition are engaged in more frequently. The emphasis of each cognitive process also varies depending on the phase of the design process. These findings have implications for how design students are educated, the skills required and how we promote creativity in design teams.

Keywords

Cognitive processes, creative thinking, critical thinking, metacognition, knowledge processing, design

Background

Creativity is the driver of competitive advantage within organizations to stay ahead of competitors (Parjanen, 2012). While being focused on creativity, contemporary design practice demands collaborative problem-solving skills, made up of critical thinking, creativity and communication (Tang et al., 2020). The front end of product design is typically considered to be highly creative (Bowen et al., 2016; D'souza & Dastmalchi, 2016; Guo et al., 2017). Many problems faced by designers are ill defined and involve techniques beyond what is achievable by one discipline so are typically solved by interdisciplinary teams (Cross, 2006; Jonassen & Hung, 2008). Recently, team design processes have gained greater attention and have focused on the social aspect of design (Bucciarelli, 1994) and on the analysis of language in design, for example, (Dong et al., 2005; Dong et al., 2013; Lloyd, 2000).

In design education, studios provide an important environment for collaborative learning where students learn to experiment and work together, using each other as a resource to iteratively generate and refine design solutions (McMahon & Kiernan, 2011; Park, 2020). Students also experience collaboration through periodic reviews known as critiques with both tutors and other group members (Gunday Gul & Afacan, 2018). However while there are efforts to provide collaborative projects both within and outside of the design studio, there is no agreed approach on how interdisciplinary teamwork should be implemented (Chou & Wong, 2015; Kiernan & Ledwith, 2014) facilitated or assessed within design education (Self & Baek, 2017). Newell and Bain (2020) found that while collaboration and teamwork is recognised as being important in design education, many design educators were not knowledgeable of the cognitive and social skills required or the structures and processes necessary to facilitate collaborative team practice.

Chou and Wong (2015) argue that design education must facilitate dialogue to encourage knowledge sharing and experience, to solve more complex design challenges and generate holistic solutions. However, the management of dialogue has had limited focus in education (Mercer and Littleton 2007). Examples of such studies are; an analysis and comparison of the conversation activities between experts and novice design teams, (Kiernan et al., 2020), a framework developed by Xun and Land (2004) using question prompts to promote peer interaction and a scaffolding discourse developed by Ferreira and Lacerda dos Santos (2009) to facilitate collaboration in design projects. However the study by Ferreira and Lacerda dos Santos (2009) showed that when students interact the dialogue is not necessarily constructive. Even when the discourse is effective students are unable to repeat the strategies as they do not readily recognise the elements of the discourse that were effective (Fredrick 2008). Park (2020) argues that a strategically designed studio structure combined with collaboration strategies are essential to give students successful learning experiences.

To develop effective approaches to team engagement, educators will need to be able to assess the collaboration process. This in turn means that the conversations and interactions of teams will require greater attention. This study explores the conversations of creative design teams to understand the cognitive processes employed by design teams and how they are engaged with, over three phases of the design process.

The cognitive processes in design teams

Three phases of the front end of design were defined for this study in line with the Design Council's model (Design-Council, 2007): problem definition, ideation and concept development. The problem definition phase involves identifying and researching an opportunity or problem, structuring research data, problem framing and creating patterns from the data that suggest solution directions (Cross, 2011). The ideation phase is focused on creating a breadth of ideas. Ideation is associated with divergent thinking with a wide search across categories of knowledge to explore new ideas (Ferreira & Lacerda dos Santos, 2009; Zhang et al., 2015). At the concept development phase the focus is to narrow the solution options with the comparative analysis and evaluation of solutions (Ulrich et al., 2011).

Group creativity can be defined as the series of interactions, knowledge exchanges and negotiations that lead to new ideas (Parjanen, 2012). While design has been associated with creativity, creativity demands not only divergent thinking, but also convergent thinking (Goldschmidt, 2016). Dong (2007) and Ferreira and Lacerda dos Santos (2009) describes how coherent design concepts come about through cycles of convergent and divergent thinking to create and then analyse and select ideas. Lipman (1989) argues that complex thinking is a combination of critical and creative thinking. He believes that both are embedded in the other and that creative thinking involves critical judgments, while critical thinking involves creative judgments. In building on the convergent and divergent aspects of design, Pacheco and Herrera

(2021) propose that there are three main cognitive processes involved in complex thinking: critical thinking, creative thinking, and metacognition. Further to this Kiernan et al. (2020) include a fourth cognitive process in the form of knowledge processing as interdisciplinary teams require the sharing and the processing of relevant information to the task at hand.

Design is solution oriented and therefore relies on both creative (divergent) and critical thinking (convergent) (Cross, 2006; Dorst, 2011). Design problem-solving, also requires metacognition to reflect on the appropriateness of the knowledge and strategies used to reach the project goals (Andres, 2013; Jonassen, 1997; van Ginkel et al., 2009). The collaborative nature of design requires knowledge processing in the sharing and integration of knowledge (Kleinsmann et al., 2012; McDonnell, 2009). Whilst acknowledging that the processes discussed below are not the only processes, they are central and therefore the focus of this paper. These four cognitive processes are described below.

Creative thinking

Creativity is the novelty and usefulness of ideas regarding products processes and services (Chulvi et al., 2012; Zhou & Shalley, 2011). Creative thinking has been defined as the ability to think divergently and generate several original ideas or solutions (Casakin et al., 2010; Goldschmidt & Tatsa, 2005) and encourages ideas that challenge the status quo (Hatchuel et al., 2017). It is made up of lateral thinking and suspended judgement to create multiple ideas (Harris, 2012; Li et al., 2007). Torrance (1968) outlines four components of creative thinking: fluency in the creation of ideas, originality in the nature of the ideas, elaboration in the expansion of ideas, and flexibility in the different categorisation of ideas. Creative thinking is the ability to view things from different perspectives and combining previously unrelated elements (Shin et al., 2012). While creative thinking is not always synonymous with divergent thinking this mode of thinking has been used to assess creativity. Tests of divergent thinking look to fluency in generating a number of ideas and originality, (Paulus, 2000; Runco & Acar, 2012). As design is solution orientated it has largely been associated with creative thinking during ideation and brainstorming (Runco & Jaeger, 2012). Designers are required to explore several ideas before they fix on one providing the need for creative thinking (Stempfle & Badke-Schaub, 2002). Previous studies assessing design performance have looked to levels of creative thinking as a performance indicator such as Badke Schaub et al. (2010). For the purpose of this paper, creative thinking is defined as:

Divergent thinking to explore and generate alternative ideas and options.

Critical thinking

While creative thinking is important in design it cannot alone address the scope of many of today's design problems. Design problems are complex, ill-defined and un-structured (Goel & Pirolli, 1989). They may have conflicting assumptions, evidence, and opinions requiring alternative solutions (Kitchner, 1983). Solving these problems therefore requires reason, argument and distributed knowledge (Jonassen, 1997; Kitchner, 1983). While creative and divergent thinking are associated with design, convergent thinking though necessary, has limited attention in the design literature (Goldschmidt 2016). It has been shown that design cycles come about through alternative episodes of convergent and divergent thinking (Dong, 2007). This is further described as a process of co-evolution to define and develop both the problem and solution together (Dorst & Cross, 2001). As ideas are created (divergent) this reveals further information or questions to be analysed about the problem (convergent thinking). As non-viable options are evaluated through convergent thinking this prompts the use of convergent thinking to generate further ideas (Ferreira and Lacerda dos Santos 2009; Stempfle and Badke-Schaub 2002; Dorst 2011). Critical thinking is convergent as it is logical and deductive to question and analyse information to make decisions (Choi and Lee 2009; Hung et al. 2008).

Critical thinking is about being able to analyse a problem, justify one's beliefs and theories, the examining of evidence and the ability to offer counter-arguments (Jonassen, 2008; Tang et al., 2020). It is analytical and focuses on essential details, the selection of ideas according to their relevance and being able to deduce options from information (Fung & Howe, 2012). Bezanilla et al. (2019) outline the following six critical thinking skills: 'Analysing/Organising; Reasoning/Arguing; Questioning/Asking oneself; Evaluating; Taking a position/Taking Decisions; and Acting/ Compromising'. Facione (2011) includes the following core skills: analysis, inference, evaluation, and interpretation. For the purpose of this paper, critical thinking is defined as:

Convergent, logical, and deductive thinking to interpret, analyse and judge information.

Metacognition

Metacognition is required for ill-structured problem-solving to plan how to tackle the problem, monitor progress, and evaluate the appropriateness of the strategies used and the knowledge of a team to reach goals and develop solutions (Andres, 2013; Jonassen, 1997; van Ginkel et al., 2009). Metacognition supports the constructing of plausible solutions for the problem and the understanding that the solution may need further evaluation (Cama et al., 2006). Metacognition relies on critical thinking to evaluate and monitor one's own reasoning (Pacheco & Herrera, 2021). Magno (2010) argues that critical thinking occurs when individuals apply metacognitive skills and strategies to produce a desirable outcome. Furthermore a relationship between creativity and metacognition has also been established (Preiss et al., 2019). Magno (2010) found that when participants demonstrated metacognitive skills, they showed higher levels of creative thinking.

For design tasks Schön's (1983) reflective practice theory proposes that design activity is based on actions and the ability to learn and make decisions from those actions. It involves a reflective conversation with the individual, the team, and the elements of the problem. Therefore, to manage their thinking processes and ability to strategise, teams must also apply metacognition which is divided into two main aspects: knowledge of cognition and regulation of cognition (Öztürk & Gürbüz, 2017). Pacheco and Herrera (2021) propose that as part of a complex thinking model, metacognition can be defined as: the knowledge capacity that a person has of their learning, the use of their cognitive abilities and the recognition of their limitations. It is the knowledge they have about when, where, and why to apply learning strategies and how these strategies can be transferred to other contexts. It is also about the recognition of other perspectives and modes of thinking; the activity of monitoring and evaluation of one's own learning and performance in action and an ability to regulate one's cognitive behaviour accordingly. In summary the main elements of metacognitive regulation are: planning, monitoring and evaluating one's problem solving strategies (Flavell, 1979). For the purpose of this paper, metacognition is defined as:

Self-reflection through planning, monitoring, and evaluating oneself or the team.

Knowledge Processing

Creativity is closely related to knowledge and domain-specific knowledge has been found to influences domain-specific creativity (An & Runco, 2016; Huang et al., 2017; Sun et al., 2020). Un-structured problem solving requires access to domain knowledge that is well organized (Jonassen, 2008),and without it solvers use weaker strategies for searching for a path or solution (Chi & Glaser, 1985). Sun et al. (2020) showed that students with a higher level of domain knowledge performed better than those with a low level of domain knowledge during tests of scientific creativity. Studies have shown that while creativity performance is influenced by domain knowledge, it is also positively impacted by creative and divergent thinking skills (Huang et al., 2017; Paek et al., 2016). Creative performance is dependent on domain knowledge and expertise, which acts as a source for creativity (Amabile et al., 2018). Creative and divergent thinking is a process of applying existing knowledge and combining unrelated knowledge in new ways (Marron & Faust, 2018). It is also about the exchange of knowledge between people to create new knowledge (Smith et al., 2005). Smith et al. (2005) found that existing and accessible knowledge impacted a company's ability to create knowledge which, in turn, increased the outputs of product and service solutions. Knowledge from several domains is also required and due to the heuristic nature of the process general process or metacognitive knowledge is also needed (Christiaans & Venselaar, 2005; Pressley & McCormick, 1995). Metacognitive knowledge can also compensate for the absence of relevant domain knowledge (Xun & Land, 2004).

Knowledge processing through collaboration can also develop critical thinking skills as the process fosters 'discussion, clarification, ideas, and evaluation of the ideas of others (Tang et al., 2020). Information processing or the gathering, interpreting and synthesizing of key information is a key process that influences team output (Mol et al., 2015). The cognitive flexibility of a team to process information is influenced by the intra domain knowledge of the team. (Furr et al., 2012). The creative output of a team also stems from diversity and a team's ability to integrate and apply diverse thought processes (Foss et al., 2008). Effective knowledge processing is critical for design teams in creating and sharing information, decision-making and coordinating design tasks to surface and integrate distributed knowledge (Détienne et al. 2012; Chiu 2002). Therefore, creative thinking, critical thinking and metacognition rely on knowledge and the ability to process that knowledge. For the purpose of this paper, knowledge processing is defined as:

The process of elaborating, explaining, clarifying, and exchanging information to co-construct knowledge.

To conclude the above cognitive process are components of what can be described as complex skills. They are both complementary and interdependent. One form of thinking relies on the others, yet they can also stand alone to address the complex problem solving that makes up design activity. However how these cognitive processes are used in the course of a design project and any variation in their use has received limited attention in the literature. By exploring the use of these four cognitive processes across the three phases described above, this study provides an understanding of how these thinking modes are applied by design teams across different stages of the design process.

Method

This research uses case studies to investigate design teams working in their normal environment in the early phases of design and focuses on the dialogue of the participants to understand the cognitive activity of the teams. The research methodology was chosen to understand the context dependent and complex interconnected processes of design. A fundamental aspect of team designing is conversation and verbal communication.

Data Collection

Four cases were selected for the study. Two of these cases had two teams within each case, this is summarised in Table 1. Each case was bounded by the context, the project, and the experience levels of the teams. Therefore, if two teams worked on the same project within the same context and from similar experience levels, they were part of that one case. The first case involved a bio-medical fellowship program (MedDev1), the second was an undergraduate project (Students), the third a professional practice case (Consultants) and the fourth an additional bio-medical case (MedDev2).

Table 1. Case study profile

Case	Project	Team Type	Team Experience
MedDev1 8 Participants (2 teams of 4)	Uncovering opportunities and the design of solutions in the area of cardiology.	Interdisciplinary, engineering (4), medicine (2), business (1) and law (1).	Experienced post-doctoral research Fellows, Industry experience 3 – 10+ years
Students 14 Participants (2 teams of 7)	Design of a crew rest for flight attendants.	Interdisciplinary, product design (10) and digital communication (3) Engineering (1)	Novice undergraduate students, year 3
Consultants 3 Participants (1 team)	Development of a software program with a user-centred approach.	Interdisciplinary interaction design, software engineering and business. Qualifications: Industrial design (2) Psychology (1)	Experienced industry-based consultants. Industry experience 3 – 10+ years
MedDev2 4 Participants (1 team)	Uncovering opportunities and the design of solutions around urology.	Interdisciplinary Bio-medical engineering (2), medicine (1) and design (1).	Experienced post-doctoral research Fellows, Industry experience 5 – 10+ years

The research data used for analyses for each project is summarised in Table 2.

Table 2. Details of data collection

	MedDev1	Students	Consultants	MedDev2
Analysed data	4 hrs of conversation recorded and analysed.	5 hrs of conversation recorded and analysed	1.5 hrs of conversation recorded and analysed	5.5 hrs of conversation recorded and analysed
Meeting durations	*Problem definition:* Team A: 1 hr 40min Team B: 1hr 52min	*Problem definition:* Team A: 40 min Team B: 46 min. *Ideation:* Team B: 1 hr *Concept development:* Team A: 30min	*Problem definition &* *Ideation:* 1.5 hrs	*Problem definition:* 3 hrs *Ideation:* 1 hr 25min *Concept development:* 1 hr

The data was collected from naturally occurring meetings in their normal setting to avoid the deformations that may be caused by setting a prescribed project. The researcher was present during all meetings where participant observation was applied, as it is suitable for investigating the rich, diverse experiences, thoughts, and activities of people (Jorgensen, 2015). The conversations of the teams were recorded as they engaged in the design process. A reflexive approach was taken to account for the presence of the researcher in the process and to negate it impacting on the research. This required the researcher remaining objective and taking an 'outsider stance' to avoid influencing behaviours or outcomes. The researcher was also a tutor for the student teams and advised all participants that the study did not impact on grading.

All participant names presented, are pseudonyms for the purpose of anonymisation.

Data analysis

Content analysis (CA) was used for the deductive interpretation of the content of text data from conversations, through a systematic classification process of coding and identifying themes or patterns (Hsieh & Shannon, 2005). The method focuses on the characteristics of language as communication, with attention to the content or contextual meaning of the text (Budd et al., 1967; McTavish & Pirro, 1990). The data was first divided into manageable chunks through the identification of topic segments. Topic shifts and changes were considered to be appropriate means of dividing segments for the purpose of analysing team progress as they tend to come about through agreement (Bublitz, 1988). The four cognitive processes identified from the literature (knowledge processing, critical thinking, creative thinking, and metacognition) were assigned to individual utterances of participants. Reliability refers to the degree to which the findings can be replicated if further studies are to be carried out. An inter-rater reliability study was conducted where another coder, coded a section of the data independently to the descriptions of the themes provided. The results show a Kappa coefficient of 0.718.

Table 3 provides an example of a topic segment from the consultant's conversation. The focus was to review a client's software application, review the navigation and information architecture and redesign it with the intended user in mind. In the first utterance, Harry combines knowledge processing to explain a feature of the program, critical thinking to analyse it and metacognition in assessing that the work involved is not a problem for the team as there is not too much information to manage. Faye responds using critical thinking to argue that the user would not have the information that they need on the screen on the initial use. Harry uses knowledge processing to explain this feature. Faye uses creative thinking to propose that they could form “headers” and “expand and contract questions”. Harry uses creative thinking to develop the solution, knowledge processing to explain it to Faye and critical thinking in the evaluation of the solution.

Table 3. Example of cognitive process codes from consultants

Topic segment	Cognitive processes
Harry: This stuff here again it’s all very rough. This is a classic example of unbelievably inefficient space use. You’d get all of this in here and it would still read properly if you designed it properly. You could have all of this in here and the rolled-up stuff and not have this presentation at all. Because this is an amalgamated part of this. So, when you click on this; it pops out that. It asks all the questions and rolls up the figure and you can have all of these states in there as well. It’s no problem, there’s not that much information there.	KP, CT, CRT, MC
Faye: The only problem we have there is if you look at initial use right. What does the user see on the screen when they haven’t filled in the questions?	CT
Harry: The questions? You fill them out and then you roll them up.	KP
Faye: Each one of these would be almost like headers.	CRT
Harry: Yeah CONSENSUS	KP
Faye: Expand and contract questions.	CRT
Harry: Yeah, and you do the questions and it roll ups and when you close it, it reconfigures the header and that gets them away from having to do this save thing which is counter intuitive because you do the questions down and the save up. So, it gets rid of the whole thing.	KP, CT CRT

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: metacognition

Findings

The teams applied all four cognitive processes during their verbal interactions to different degrees to support creative problem solving. The proportion of use over all cases was:

1. Critical Thinking (40%)
2. Knowledge Processing (34%)
3. Metacognition (27%)
4. Creative Thinking (7%)

(Note: Total percentage may be more than 100% as some utterances were coded to more than one category.) The limited use of creative thinking during the front end of design is a surprising finding as creative thinking is largely associated with creative activities such as designing. To gain a deeper understanding of how these cognitive processes were employed it is necessary to examine their use at the different phases of the design process.

Table 4 provides the cognitive processes used, in order of frequency, for each phase and Figure 1 shows the distribution at each phase. There were differences in the use of the cognitive processes between the phases. This can be attributed to the different objectives at each phase of the design process. The problem definition phase is focused on structuring the requirements for the task, the ideation phase is focused on divergent thinking to create a breath of ideas while the concept development phase is focused on the evaluation and refinement of ideas. How each cognitive process was used across the design phases is discussed in the next section.

Table 4. The order of ranking the activities for each phase across all of the cases

Problem definition	Ideation	Concept development
Critical Thinking (43%)	Knowledge Processing (36%)	Knowledge Processing (47%)
Metacognition (35%)	Critical Thinking (31%)	Critical Thinking (38%)
Knowledge Processing (31%)	Creative Thinking (23%)	Metacognition (14%)
Creative Thinking (2%)	Metacognition (13%)	Creative Thinking (6%)

Note: Total percentage may be more than 100% as utterances were coded to more than one category

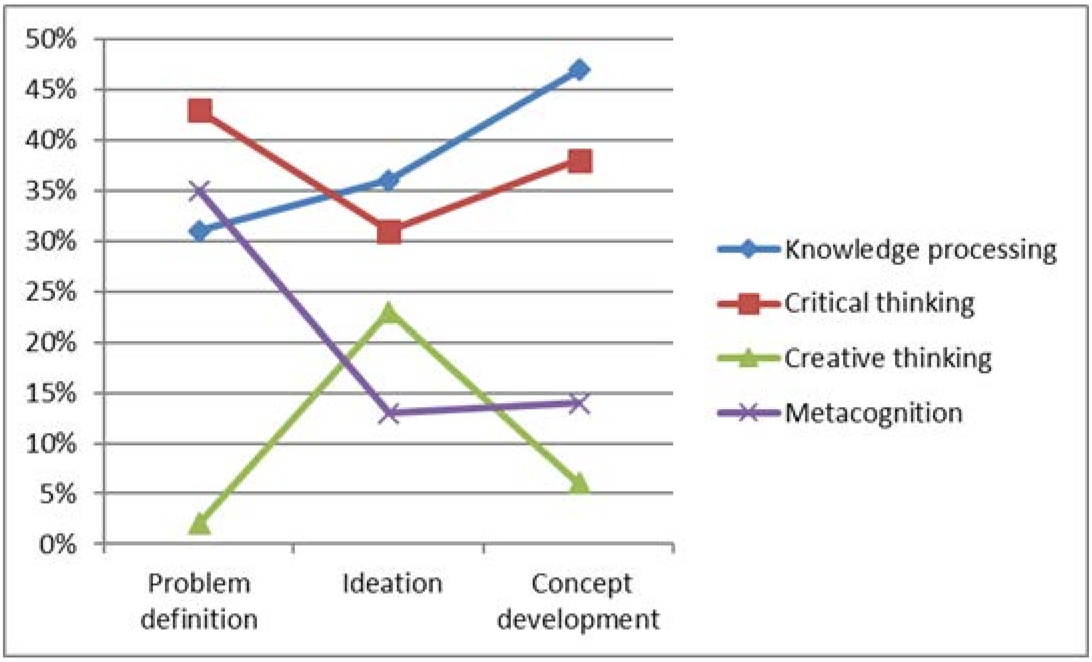

Figure 1. The distribution of the cognitive processes across the design phases

Knowledge processing across phases

Knowledge processing was at significant levels across all phases of projects and levels increased over the phases of projects. This is surprising as the processing of information would have been expected to be at its highest at the beginning of projects as the team members were structuring the requirements. At the concept development phase, knowledge processing was at its highest level to show that knowledge and information exchange is emergent throughout the process. As the team members developed ideas this forced the acquisition of new knowledge in the evaluation and development of solutions. Knowledge processing was also critical in the explanation of solutions to other team members. Below is an example of a topic segment that shows how the Consultants used knowledge processing to share information. During a review of their client's product, Harry externalising his knowledge of the application for the team. The sharing of information by Harry prompts Faye to request further elaboration. Harry responds by providing further knowledge about the client's product showing how knowledge is co-created by the team.

Harry: See the competitors here now this screen shot hasn't got one. Basically, those competitors here are not the same as those competitors here, so you know how you add competitors you asked them how do you delete and add competitors? So, it's down there, you put them in down there. It's in the standard opportunity but then they have this field called competitors or main competitors here and it's not them.

Faye: And how do you fill in those main competitors? That's the question I was asking.

Harry: You double click on the little pencil, and you dump them in but it's just text.

Critical thinking across phases

Critical thinking was at its highest level at the problem definition phase. While it dropped at the ideation phase it was still used significantly, which can be attributed to a co-evolution of developing the problem and solution together. This was reflected in the combined use of both divergent and convergent processes in the form of critical and creative thinking. The teams used critical thinking for further analysis of the problem as ideas posed new questions about the problem space and uncovered emerging sub problems and constraints. For example, ideas proposed with creative thinking could involve a radically new way of doing something leading the team to re-examine new aspects of the problem which required further critical thinking and the processing of information. The following is an example of this co-evolution process from the Students Team B. The team were designing a rest area for airline crews and had established that they needed to provide a changing room for flight attendants.

Brian: I think that the space under the stairs is used as storage. We could convert that into some sort of changing room. (Creative thinking)

Lisa: But in reality, we need to get the size of that because there is no point in saying we're putting it in there and then we can't physically get it in there. We need to know the rise of it and the slope. (Critical thinking)

Brian proposes using the area under the stairs in the crew rest. Upon the creation of the idea the team then recognise that they need to gather more information about this area and analyse it further. Lisa argues that they need to know more about the problem state before they continue to propose solutions (Figure 2).

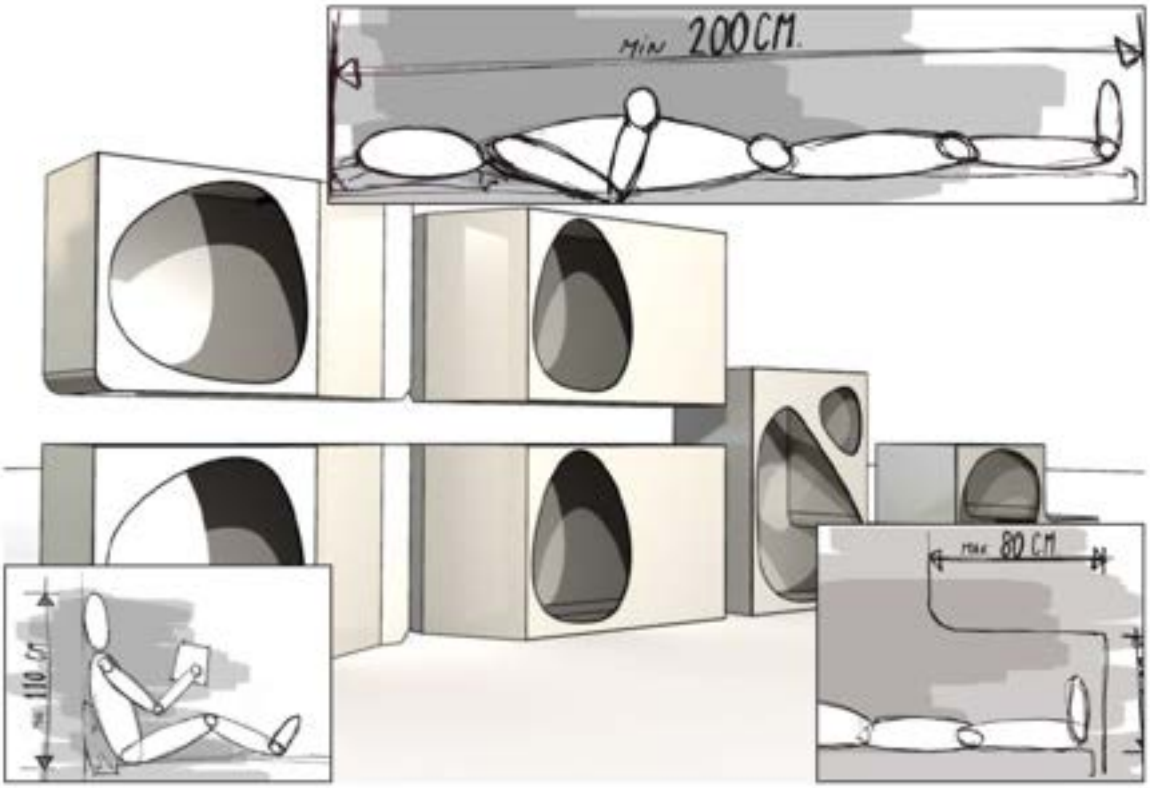

Figure 2. Exploration of crew rest area outputs

Creative thinking across phases

As creative thinking levels increased, critical thinking levels decreased. Creative thinking was at the highest level at the ideation phase while critical thinking was at the lowest level at this phase. These modes of thinking are opposite in nature, so these findings are apt for this stage in the process. The focus at the ideation phase is to create multiple ideas. An overemphasis on critical thinking in the evaluation of ideas could restrict the multiplicity of ideas. At times teams were observed critiquing ideas and discounting them quickly rather than considering how they could be adapted or further explored. Due to space restrictions a member of the Students Team B proposed combining an elevator as a changing room which was critiqued by another member very quickly:

> *Max: It's very hard for it to be an elevator at the same time. If someone is changing and someone else wants to go up or down, that's not possible.*

Runco and Acar (2012) have shown that divergent thinking is synonymous with creative potential. For early idea generation, the aim is to explore and generate a depth and breadth of solutions and withholding judgment on the value of concepts to maximise the potential for optimal solutions (Casakin et al., 2010; Zhang et al., 2015).

Creative thinking had very limited use at the problem definition phase. This is surprising as creative thinking is considered to be a core skill for designers (Kelley, 2001; Stempfle & Badke-Schaub, 2002; Yilmaz & Seifert, 2011). It also had limited use at the concept development phase and was used to revise ideas for solutions upon critical analysis of those solutions. The following is an example of an interchange between knowledge processing, critical thinking, and creative thinking from the MedDev2 team at the concept development phase. Riona uses knowledge processing to explain a proposed concept (Figure 3). Once Liam understands the concept, he analyses it and uses critical thinking to argue that the product may not function correctly. The evaluation prompts Riona to use creative thinking to further build on the idea and develop the solution of a seal.

> *Riona: It comes from the base out to there like this, bear with me. Say this is flush with the skin and then this from the side is protruding out there. (Knowledge processing)*
>
> *Liam: But it still begs the question, I'm just imagining if drips come out here, they are going to be funnelled back. (Critical thinking)*
>
> *Riona: Yeah, there would have to be a seal. Like what you said there, can you bring it out and let it funnel into the bag? (Creative thinking)*

Figure 3. Early prototype

Metacognition across phases

Metacognition was also at highest levels at the problem definition phase dropping significantly over the next two phases. The problem definition phase requires considerable planning and strategising within the team to determine the best approach to working through the project which can account for these levels. The following is an example from the problem definition phase where the MedDev2 team monitored how the team were handling one of the needs/requirements that came from their research findings. There is a difference between Christy and Kieran's interpretation of the requirement. Christy argues that the criteria Kieran uses are not written into the need. He argues why convenience is an important factor in the assessment of the need. Through the application of critical thinking to assess the need and metacognition to monitor and evaluate how the team has managed this need, Christy convinces Kieran to incorporate these "*measurable outcomes*". This managed to elevate the importance of the 'need' amongst the team members.

Christy: You said you want to achieve real time feedback of blood pressure through a non-invasive technique. (Critical thinking, metacognition)

Kieran: Efficiency and convenience, they're the two benchmarks. (Critical thinking)

Christy: Well, that's not how it's written in the needs statement. Are we just assuming that it is, and we score it through non-invasive techniques, to make the procedure more accessible and convenient? (metacognition) In my mind if the need statement was, need a way to provide real time feedback of blood pressure to the clinician, then in my mind it scores at least a three because it's completely inaccessible at the moment, with invasive monitoring. (Critical thinking) There are complications which cost money and it requires a HDU overnight. (Knowledge processing)

Kieran: Fair enough, I think that is where that one was going too. There's no measurable outcome in the needs statement. If we can build those in as measurable outcomes, then you're definitely addressing convenience at least or access. (Metacognition, critical thinking)

Critical thinking and metacognition were often used in combination, while critical thinking was focused on the analysis of the task, metacognition focused on the analysis of the team and individual's performance.

Overall, the findings show that creative team cognition involves a continuous alternation between each of the cognitive processes outlined. Each cognitive process was complementary and interdependent. The findings also show that the emphasis of each cognitive process varied over the design phases and an overuse of some cognitive processes at certain phases could also be counter-productive such as applying critical thinking in the judging of early ideas instead of producing a breath of ideas. In summary, the cognitive processes used were dependent on the objectives at each phase of the design process.

- Knowledge processing increased across the design phases showing that the requirement to agree on new information continues throughout the design process.
- Critical thinking was used extensively across all phases of the design process decreasing only slightly at the ideation phase.
- Creative thinking was the least frequently used cognitive process across all phases rising significantly only at the ideation phase.
- Metacognition was used frequently during the problem definition phase to manage the uncertainty and diversity in perspectives at this phase.

When critical thinking and metacognition (convergent in nature) levels were high creative thinking (divergent in nature) levels were low.

Discussion

Much of the literature in design has emphasised the importance of creativity for designers. For example, both Kelley (2001) and Nussbaum (2013) promote the principle that creativity is a key aspect of designing in teams. It is also an essential component of design education but provides challenges for educators in how to teach it (Wong & Siu, 2012). Creativity has been described in terms of sudden emergent bursts of ideas, described as creative leaps (Dorst & Cross, 2001). These findings problematise such conceptions of creativity suggesting it is important to contextualise creativity constructs within the broader problem-solving process. The data from this study suggest that creativity in design is not just about applying creative thinking. It is as much about knowledge processing, the application of critical thinking to analyse that knowledge, creative thinking to come up with ideas and critical thinking to analyse and refine those ideas. In this way creativity can be conceptualised as a considered process requiring the successful assimilation of several cognitive processes. Through metacognition and reflection on the process teams and individuals can strategise on how to conduct a task, reflect on the effectiveness of those strategies, and revise their course of action where necessary.

What was unexpected in the findings was the level of engagement with each cognitive process. Creative thinking accounted for only 7% of overall cognitive activity. While creative thinking can be associated with creativity and the generation of ideas, idea generation is also stimulated by engaging with other cognitive processes. This study found that design behaviour shifts from divergent behaviour when engaging in knowledge processing and creative thinking, to then convergent and analytical behaviour during critical thinking and metacognition. Critical thinking dominates the process at all stages. Once information was shared, critical thinking was applied in a sense making process where emphasis was placed in finding relationships and patterns between elements. While knowledge processing was used to expand the problem space, critical thinking was used to structure and analyse this information. By questioning and critiquing the problem and reframing it from different perspectives this creates the opportunity to then apply creative thinking to generate solutions. Therefore, by encouraging strong critical thinking ability in design teams this can pave the way for creative solutions.

Knowledge processing accounted for 34% of team activity. Knowledge sharing and integration have been shown to be critical to performance in design (Guo et al., 2017) and in line with the literature a strong relationship between the acquisition of knowledge and creativity was shown (Christiaans & Venselaar, 2005; Sun et al., 2020). Knowledge processing increased across the phases showing that knowledge is emergent throughout the process and not just a focus at the problem definition phase.

Metacognition accounted for almost a third of activity and was frequently used to prepare how to solve the problem and structure disparate information. It involved teams repeatedly reviewing their own progress, recognising gaps in knowledge, and reflecting on the effectiveness of their progress.

The different phases of the design process were found to call for an emphasis on different cognitive processes. Due to the complexity of design problems, teams must first structure the problem before any solution searching can proceed as advocated by Zenios et al. (2009). The problem definition phase was predominantly independent of solution generation and hence creative thinking was at its lowest level. Solution focusing during problem definition could narrow the focus of the problem space too early and limit the scope for new ideas. The findings show that this phase requires mainly critical thinking to analyse and structure the project elements. Metacognition which has been linked to resolving uncertainty was at its highest levels at this phase, this was the phase where the teams were required to consider how to conduct the project and involved cycles of planning tasks, monitoring how the project was being structured and evaluating the result. As expected, creative thinking was highest during ideation, but still used less than knowledge processing and critical thinking. At the ideation phase knowledge processing can be attributed to the co-evolution account in the literature of creative design which is not a ‘creative leap’ from the problem to the solution space but an evolution of both where one informs the other (Maher & Tang, 2003). Critical thinking was used for further analysis of the problem as ideas posed new questions about the problem space and uncovered emerging sub problems and constraints. However, a balance is required as it was found that too much critical thinking at the ideation phase may restrict the fluency of ideas. Studies have also found a correlation between the high amount of ideas and ideation success (Goldschmidt & Tatsa, 2005; Moreno et al., 2014). The concept development phase called for further knowledge processing as the critical analysis of solutions provoked further questions and information seeking. Therefore, as ideas emerge further knowledge is required to understand the impact of solutions.

Recommendations for Design Practice and Design Education

Researchers have argued that educational institutions need to promote complex thinking amongst students (Pacheco & Herrera, 2021). Wong and Siu (2012) argue that design education has been focused on producing creative outputs rather than the processes to arrive at creative outputs. They suggest that the thinking skills of designers requires more focus. With an increase in team work both in industry and education an understanding of the verbal interactions between team members is critical to uncover the thinking engaged with in order to contribute to creative processes as advocated by Gustina and Sweet (2014). This research has contributed to this understanding to reveal the cognitive process used during different phases of the creative design process. The findings confirm that effectiveness of the use of these cognitive process is contingent on good collaboration and communication (Tang et al., 2020). This points to the need for careful facilitation of team discussion to encourage designers to engage in productive dialogue. Tutors or managers can act as facilitators to prompt and scaffold conversation to encourage the cognitive processes outlined. Designers need to be encouraged to be strong critical thinkers by learning to question information and challenge conventional modes of thinking. They need to support this mode of thinking with strong knowledge of a domain (Sun et al., 2020). Knowledge acquisition will continue throughout the project and where the team is lacking in knowledge they will need to consult with experts. Designers also need to be able to be able to alternate on the fly between creative (divergent) and critical (convergent) thinking to firstly explore potential solutions and to then analyse the appropriateness of these solutions. The process can be supported by metacognition to plan, monitor and evaluate progress.

Attention should also be given to the purpose of the phase, for example creative thinking at the problem definition phase may restrict the problem definition stage if the focus is on solution generation rather than problem structuring, while too much critical thinking during the ideation phase could stem the flow of ideas.

The degree and experience and proficiency of educators to implement team work, assessment structures and grading means that educators may place more emphasis on project outputs rather than on the process inputs and the collaborative exchanges required to work effectively within a team (Riebe et al., 2016). The finding of this study can help to provide an understanding for educators of what constitutes productive dialogue while also providing the means and support to implement, facilitate and assess teamwork.

Limitations

Only two cases could be compared for the ideation and concept development phases. This is a limitation of the study and while the findings are not generalisable the questions it raises are generalisable. Only the problem definition phase was captured from the MedDev1 case. The Consultants meeting was predominantly a problem definition meeting and has been defined as such for cross case comparisons. However, due to the nature of the project the team also came up with ideas in this meeting. They did not hold specific ideation meetings and further design developments were done by individuals.

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Perception over the use of traditional and digital mediums within the design process: A questionnaire study on design students

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Abstract
The purpose of this study was to explore design student's perceptions over traditional and digital mediums within the design process. In this research, a convenient sample of design students was selected from two universities between Latin America and North America to respond a questionnaire which inquired for the design steps and the type of tools they used. The importance of traditional medium in the design process has been widely researched (e.g. Goldschmidt, 1991; Suwa et al., 1998; Tang & Gero, 2002). In a similar manner, digital medium has evolved in the design practice and researchers have looked at how the use of digital tools affect the design process (Salman, et al.2014). Multiple studies have argued that some stages of this process cannot be supported by digital medium tools (e.g. Bilda & Demirkan, 2003; Kwon, et al., 2005; Meniru, et al., 2003; Stones & Cassidy, 2007). In contrast, digital medium stimulates the occurrence of design patterns and epistemic actions (Yu, et al. 2015: Chandrasekera, 2014). Digital medium will require the development of new knowledge which may affect the designer's role and the education practices of new designers. The outcomes of this study will help design educators to understand design students' preferences in using digital tools and develop curriculums accordingly. In addition, it will aid software developers to better understand, cater to design students' needs and take advantage in the growing shift from traditional to digital medium.

Key Words
design process, design pedagogy, design method, design medium, digital tools, sketching

Introduction
Research on how the design process can be explained and documented began with Archer (1963) moving forward into multiple studies to better understand how designers think, develop their ideas and generate design solutions (e.g. Darke, 1979; Cross, 1982; Goldschmidt, 1991; Suwa, et al., 1998; Tang & Gero, 2002). However, better understanding how the design process unfolds and how multiple design mediums affect this process remains an ongoing area of exploration. Design mediums are defined by the type of design tools that are used in the design process. This study focused on two design mediums. First, the *traditional medium* constituted of non-digital design tools, such as pen and paper, sculpting and modeling materials, etc., and second, *digital medium* structured by digital tools such as vectorial software, modelling software, photo editing software, etc.

The importance and relevance of both design mediums within the design process has been acknowledged in previous research. For Rittel and Weber (1973), the design process is a solution testing method which tackles wicked problems. Such problems will never have a final solution and must be revisited over and over again. When facing wicked problems designers analyze the problem re-examining ideas (Cross, 1990). In this re-examination process, traditional media has been found crucial for idea's reinterpretation and evolution (Goldschmidt, 1991; Suwa, et al., 1998; Tang & Gero, 2002). One of the main reinterpretation attributes in traditional media is *emergence* (Oxman. 2002). In contrast, digital media has been found restrictive to generate and support such attribute (Purcell & Gero, 1998; Oxman, 2002). Nonetheless, digital media can enhance the design process differently. In the study conducted by Yu, et al. (2015), digital tools evidenced the occurrence of *design patterns*. Design patterns are defined as core solutions to problems which can be repeated over and over again, always generating different outcomes. Furthermore, digital media permits the manifestation of *epistemic actions*. Epistemic actions are defined by Kirsh and Maglio (1994) as actions which free cognitive load through physical manipulation of the problem while looking for a solution, instead of, thinking on the solution prior to the manipulation process (pragmatic action). These attributes of digital media deliver a more efficient design process and liberate cognitive load.

This study collected data using a questionnaire from second year design students from multiple design majors in two universities between Latin America and North America. This questionnaire intended to better understand their preferences in design mediums as related to different design stages of the design process.

Literature Review

According to Gericke and Blessing (2011), there is no definitive design methodology ranging in different proposals between different models. Nonetheless, multiple shared stages in those models have been demarcated within them (Gericke & Blessing, 2011). These stages are subdivisions of the design process often defined as design phases. Three main stages were identifiable as the most common according to Gericke and Blessing (2011): a *problem definition stag*e, a *conceptual design stage* and a *detail design stage*. The type of design mediums used in each stage varies according to the needs of the designer as well as specific stage's properties (Ibrahim & Rahimian, 2010). Since traditional media rouses idea reinterpretation and emergence, this study estimated that, such media was more frequently used in the problem definition and conceptual stages. In contrast, due to attributes of efficiency and repetitiveness, digital media was expected more frequent in the detail design stage.

Design Mediums: Between Traditional and Digital

Design mediums can be divided in traditional media and digital media. Traditional media is typically used through the direct manipulation of pen and paper or by the generation of tridimensional models (Cross, 1990; Ibrahim & Rahimian, 2010; Shih, et al., 2017). Moreover, the relevance of making and iterative reflection to enhance cognitive processes in the creative process has been addressed in the past. Traditional media has been frequently used to conceptualize ideas which can be later revisited by designers. In contrast, digital media has been more frequently used to focus on details and obtain realistic results (Ibrahim & Rahimian, 2010; Shih et al., 2017). According to the designer's intrinsic skills and interests, each medium has its own characteristic and properties which can help attain the desired results.

According to Oxman (2006), there are four levels of medium interactivity ranging from paper based representation (traditional drawings) found in basic levels to completely digital environments in the highest levels. In this categorization, the first level involves physical interaction between the designer and the environment or representation, while the remaining three levels require an increase in digital interactions in non-physical environments, as well as a more developed designers' skillset**.** Within the first level, traditional medium tools are most commonly used to move the design process forward, more specifically, drawing regularly refereed as *sketching*. In contrast, digital mediums are most commonly used in the remaining three levels. The importance and relevance of sketching for the design process has been amply researched. For Cross (1990) sketches can be found all throughout the design process in various levels of complexity according to the designer's needs. He understood sketching not only as a communication tool, enhanced with models or tangible supports for designers to express their thoughts, but also as the way designers manage their thought processes, represent their early ideas and further evolve the ideas into final proposals or solutions. In summary, sketching was seen not only as a traditional medium tool used by designers to represent an idealized world, but rather as an ideation tool to develop their own design process. Through a series of protocol studies, Goldschmidt (1991) was able to expose the important relationship of creativity and sketching by evidencing through it the reflection process between ideas. Through the action of sketching and its observation, designers reflect discovering new attributes which move the design process forward. This iterative action *between seeing as* and *seeing that* was definite to propose an interpretative dialectic which enhanced creativity within the design process (Goldschmidt, 1991). In addition, Purcell and Gero (1998) stated that in order to be able to reinterpret sketches, attributes of ambiguity and density were crucial. To do so, the image or drawing in hand must be decomposed and recomposed into a new image which will give origin to creative moments within that process. Furthermore, according to Purcell and Gero (1998), these attributes are missing in digital mediums. Design students perceive and value sketching as a necessary skill, however, they find this type of traditional medium time consuming, expensive, lacking in detail and less efficient to achieve more realistic results (Ibrahim & Rahimian, 2010; Jonson, 2005).

In higher levels of medium interactivity, digital design has been emerging as a new practice of design. The impact of such is still divided and researchers have approached how digital mediums affect the design process (Salman et al., 2014). Multiple studies have argued that tools in this digital medium are still incapable of supporting idea development in conceptual stages (e.g. Bilda & Demirkan, 2003; Kwon et al., 2005; Meniru et al., 2003; Stones & Cassidy, 2007). The issue is that digital medium tools evolve rapidly. According to Yu, et al., (2013) the usage of digital medium tools in the design industry has changed. Sketching or drafting software which used bi-dimensional platforms, has been replaced by more diverse and elaborated tools which permit deeper thought processes positively affecting the design process (Hernandez, 2006). In addition, designer's need for more elaboration and less ambiguity in traditional medium has opened the opportunity for digital mediums to evolve and become more intuitive to satisfy this need. This evolution is currently permitting digital tools to be present in the design process from the beginning to the end (Shih et al., 2017).

Table 1. Challenges and benefits of traditional medium and digital medium.

Challenges and Benefits of Mediums		
	Benefits	**Challenges**
Traditional design medium	1. Physical interaction. (e. g. pen and paper)	1. Less capability to zoom in or zoom out
	2. Intuitive to use	2. Difficult to alter design proposals
	3. Simple supplies required	3. Fewer visualization details
	4. Easy to propose multiple design alternatives	4. Low efficiency in the process
	5. Attributes of ambiguity and density	5. Low detail and accuracy possibilities
	6. Multiple idea iterations	6. Tool specificity according to the design stage
Digital design medium	1. Liberates cognitive load	1. Complicated skillset required to use
	2. Design manipulation through zooming, omitting elements, panning, rotating, etc.	2. Lack of ambiguity and density
	3. Uses design patterns	3. Facilitate idea iteration
	4. Possibility to undo actions	
	5. Better visualization with more detailed and realistic results	

The study conducted by Jonson (2005) challenged dominant views in literature in which sketching was seen as the most important ideation tool in contrast to digital tools which were more used for representation, modeling and detailing. Verbalization was found to be vital within the design process generating more *A-ha* moments mediating between traditional and digital tools (Jonson, 2005). In an experimental setup, Jonson (2005) combined traditional and digital mediums to conclude that the combination of these mediums, intermediated by verbalization, generated more interactions which positively affected creative thinking. Such finding may suggest that ideation thrives under dynamic setups rather than under organized conditions.

This study does not intend to discern between traditional or digital mediums to see which one is better than the other. In contrast, the advantages of mixed medium environments in enhancing creativity has been supported (Salman et al., 2014; Shih et al., 2017). Table 1, summarizes and contrasts the benefits and challenges of traditional design media versus digital design media. Each design media has its own advantages and disadvantages and each can be enhanced by switching actions to compensate for weaknesses. Hence, mixed mediums are currently preferred by designers since they stimulate creativity by switching actions between them (Shih et al., 2017). Nevertheless, neither traditional nor digital mediums are solely used to currently handle the complete design process. Striving to fill the transition gap between the two mediums, integration mechanisms have been proposed to facilitate this between them, such as the Digital Sketch Modelling method proposed by Ranscombe, et al. (2017). In addition, shifting between multiple digital tools can replace the apparent dynamism of traditional media (Jonson, 2005; Salman et al., 2014; Shih et al., 2017). In conclusion, new digital medium usage will require the development of new knowledge which may affect the education of new designers as well as the designer's role. Also due to the relevance that personal attitudes have towards the process of learning (McLaren & Stables, 2008), design student's preferences should be considered to adjust the instruction of design knowledge to effectively satisfy their needs and maintain the expected design outcomes. It became important for this study to better understand the perception and usage preferences of diverse mediums in current design students.

> *RQ1. What types of design mediums are more frequently used by design students in diverse stages of the design process?*
>
> *RQ2. What is the perception of design students over traditional and digital design medium?*

Method

A questionnaire was conducted to a convenient sample of 54 participants consisting of junior year undergraduate design students. For this study two universities were selected, one located in Colombia, Latin America, and the other in the Midwest of the United States, North America. In both locations, mandatory design studio courses for students above junior level were selected to conduct the questionnaire, hence the gender conformation of the sample was completely random according to each undergraduate program characteristics. The questionnaire consisted of two sections, the first section constituted demographics and the second a combination of open ended questions and multiple choice questions using Likert scales to measure several levels of response. In this section, the multiple stages of the design process and the students' perception on the two design mediums were explored. Design students were required to arrange the steps of their own design process, manifest which kind of tools they used for both medium and evaluate the importance and benefits of both mediums in relation to the steps. The statistical package/software SPSS version 24 was used for statistical analysis.

Analysis and Discussion

The total sample of 54 participants presented an age mean score in years of 21.81 ($SD = 1.65$) distributed according to geographical location for each university in 57.4% for Latin America and 42.6% for North America. For the complete sample size, 37% were design students in Junior level while the remaining 63% were design students from senior level. A total of 79.6% were female with the remaining 20.4% of male. For the female group 48.8% were based in the Latin America university and 51.2% were in the North America university. For the male group, 90.9% were in the Latin America university and 9.1% in the North America university. Table 2, displays general descriptive statistics of the sample. In relation to the fields of design activity, 59.2% of participants manifested activities in interior design, 57.4% product development, 25.9% graphic design, 5.5% architecture, 1.8% apparel design and 14.8% manifested activity in other types of design, such as experience design, furniture, and packaging.

Table 2. Sample's descriptive statistics.

Sample General Descriptive				
		Gender		Total
		Male	Female	
Latin America University	Count	10	21	31
	% within University	32.3%	67.7%	100.0%
	% within Gender	90.9%	48.8%	57.4%
	% of Total	18.5%	38.9%	57.4%
North America University	Count	1	22	23
	% within University	4.3%	95.7%	100.0%
	% within Gender	9.1%	51.2%	42.6%
	% of Total	1.9%	40.7%	42.6%
Total	Count	11	43	54
	% within Universities	20.4%	79.6%	100.0%

The questionnaire required seven defined design steps of the design process to be arranged in chronological order according to each respondent's perception. The defined design steps arranged in order of importance according to the respondents' answers were: *research, analysis, conceptualization, ideation, sketching, modeling* and *representing*. Of the total sample, 11% proposed new design steps: v*erification, observation* and *prototyping, verification* being the most common with a 66.7% share of 11% total. For the purpose of this study and in relation to the design method stages of the design process proposed by Gericke and Blessing (2011), *research* and *analysis* were linked to the problem definition stage, *conceptualization, ideation* and *sketching* to the conceptual design stage and *modeling* and *representing* to the detail design stage. Each design step was evaluated according to the level of importance given by the participants in a seven point Likert scale. The design steps which had the higher scores were *research* with a mean score of 6.69 ($SD = 0.61$), followed by *modeling* with a mean score of 6.29 ($SD = 0.88$) and *analysis* with a mean score of 6.26 ($SD = 0.82$). In contrast, the only design step that had a mean score below 6.0 was *sketching* with a mean score of 5.39 ($SD = 1.204$). A one sample t-test with an alpha level of .05 was conducted between the total sample mean score for all steps 6.14 ($SD = 0.52$) and the mean score of *sketching* which displayed statistical significance ($t(53) = -4.621$). This finding displays that *sketching* is perceived as the less important step of the design process. This does not necessarily suggest that students perceived sketching as not important in the design process. In addition, it is relevant to keep in mind that this step had the highest standard deviation of the mean scores for all steps. Therefore, we may infer that the perception of participants about the importance of sketching is the most diverse between subjects. In relation to the three stages of the design method, the highest score was for the *problem definition stage* with a mean score of 6.47 ($SD = 0.62$), followed by the *detail design stage* with a mean score of 6.16 ($SD = 0.75$) and in last place the *conceptual design stage* with a mean score of 5.93 ($SD = 0.70$). An omnibus ANOVA was conducted between the three stages with statistical significance ($F(2,96) = 12.454$). In post hoc analysis using a Bonferroni adjustment, the pairwise comparisons displayed statistical significance between the *problem definition* stage and the remaining two stages. From this we concluded that for participants the problem definition stage was the one of higher importance. Research has demonstrated that problem framing is a very important stage in the design process (e.g. Rittel & Webber, 1984; Dorst, 1996; Lawson, 2004). Problem definition defines the required approach to solve the design problem and prepares the mindset to use the required tools to accomplish that solution. Table 3, shows information regarding the design steps evaluation and the type of medium used.

Table 3. Design steps evaluation and type of medium.

Design Stages and Steps					
		Steps Grading		Medium used %	
Design Stages	**Design Steps**	**Mean**	**SD**	**Traditional**	**Digital**
Problem Definition	Research	6.69	0.609	88.9%	55.5%
	Analysis	6.26	0.828	61.1%	68.5%
Total stage		6.47	0.625		
Conceptual Design	Conceptualization	6.09	0.925	70.4%	72.2%
	Ideation	6.24	0.799	42.6%	77.8%
	Sketching	5.39	1.204	35.2%	92.6%
Total stage		5.93	0.704		
Detail Design	Modeling	6.26	0.880	98.2%	20.4%
	Representing	6.10	1.063	92.6%	46.3%
Total stage		6.16	0.752		
Total of All Stages		**6.14**	**0.525**		

The use of traditional and digital mediums was also contrasted with the seven design steps previously discussed. The steps which had the higher usage of digital mediums were *modeling* with 98.1% of the total sample size followed by *representing* with 92.6% and *research* with 88.9%. In contrast, traditional mediums had higher usage in *sketching* with 98.1% of the total sample size followed by *ideation* with 77.8% and *analysis* with 68.5%. Furthermore, 94.4% of the total sample size believed that digital media is more beneficial than traditional media in the design steps overall. Open ended questions were asked to better understand why digital mediums were believed to be more beneficial. Answers varied between participants, but the most frequent reasons related to efficiency and realistic results. Supporting previous research (Ibrahim & Rahimian, 2010), apparently speed and efficiency in the process are very important to design students and such is better achieved through the use of digital mediums. Some of the answers were:

> *"I can be more creative with my pencil, but sometimes making it with a program is faster"*

> *"Digital media speed up the process and provides realistic results"*

> *"You can show a client what the space will look like and with VR design they can actually walk through it at a human scale"*

> *"Better idea representation permitting the client to better understand the idea, its benefits and innovation"*

Additionally, all participants were asked if they use sketching in the design process with a 90.7% of them answering yes. Furthermore, when they were asked if they used digital tools, the total of 100% of the sample answered yes. We were expecting to find that all participants used sketching in the design method in accordance to previous research which has demonstrated the importance of sketching. For the participants who responded that they used digital tools in the design process, which in this case was the total of the sample size, we asked what kind of digital tools they most frequently used. The most frequently used digital tools were modelling tools with a 96% of the total sample, followed by photo editing tools with 68% and vectorial drawing tools with 62%. In contrast, digital tools used for sketching were only used by 14.8% of the total sample. Since most of participants use sketching in the design process and all of them use digital tools, this finding opens the possibility for future research to address sketching through new digital tools which may positively contribute to the ideation process.

Finally, a five point Likert scale to measure the level of agreement or disagreement of participants in various attributes for traditional and digital mediums was applied. Table 4, exhibits the level of agreement evaluation between digital and traditional mediums for each attribute.

Table 4. Level of agreement between digital and traditional mediums.

Agreement Evaluation Between Medium				
	Traditional		Digital	
	Mean	SD	Mean	SD
Helps to organize ideas	3.70	0.952	4.17	0.717
Helps visualize final idea	3.30	1.160	4.85	0.408
Appealing to clients	3.12	1.166	4.94	0.235

The scale ranged from *strongly agree* (5) to *strongly disagree* (1). For the attribute *helping to organize ideas*, digital medium obtained a mean score of 4.17 (*SD = 0.717*) in contrast to traditional medium which obtained a mean score of 3.70 (*SD = 0.952*). A dependent t-test was run with statistical significance (*t(52) = 3.165*) displaying that digital media help to better organize ideas. For the attribute *helps visualizing the final idea*, digital medium obtained a mean score of 4.85 (*SD = 0.408*) in contrast to traditional media with a mean score of 3.30 (*SD = 0.160*). A dependent t-test was run with a statistical significance (*t(53) = 1.881*) displaying that digital media helps to better visualize the final product. For the attribute *appealing to clients*, digital media obtain a mean score of 4.94 (*SD = 0.235*) in contrast to traditional media with a mean score of 3.12 (*SD = 1.166*). A dependent t-test was conducted with a statistical significance (*t(51) = 10.832*) displaying that digital media is perceived to have more appeal to the viewer. Participants containing missing data were not considered for the dependent t-test evaluations. Effect size was measured for the three dependent t-tests with a moderate effect of 0.43 standard deviations for the attribute *helping to organize ideas* and high effect for attributes *helps visualizing the final idea* and *appealing to clients* with 1.30 and 1.50 standard deviations respectively as by Cohen. Power was measured for all three dependent t-tests, being the lowest of the three *helping to organize ideas* which displayed a high level of power () with a probability of 7.9% Type II error. This information supports that participants' perception over digital media is that digital media is more beneficial in helping designers organize ideas, better visualize the final product and make ideas more appealing to clients.

Conclusions

The findings on this study reveal the importance digital mediums currently have in the design method according to design students' perception. Of three proposed stages for the design method, stages in which there was higher influence of digital media were more relevant. The full sample manifested the importance of digital medium within the design process. Traditional medium is considered very important in the design process, nonetheless, for current design students the application of such media may seem of lesser value than that of digital medium. Digital medium offers attributes of effectivity, time efficiency and realistic results, which can be adapted to strengthen traditional medium as well. While traditional medium tools such as sketching continues to be of relevance in the design process, digital medium still has not found the way to make digital tools efficient and practical to satisfy the user's sketching needs.

As initially stated, was not to suggest which medium is better than the other. The main purpose was to expand in the better understanding of design students' preferences and perceptions on using these mediums. Findings suggest that digital medium is overcoming traditional medium and it is currently being used along the complete design process. In addition, the advantages of mixing mediums could be further explored in design academia. Students are aware of the relevance of sketching in the design process. New medium and tool shifting practices, more dynamic setups and increased group interaction to augment verbal communication may enhance creative moments. Design educators must find new ways into how to adapt these digital media tools to reinforce stages of the design process, such as the conceptual design stage. Curricular approaches and methodologies in design studio courses which traditionally used pen and paper are required to incorporate digital medium tools. Future research is needed into how more intuitive and dynamic digital tools may positively affect problem definition and conceptual stages of the design process. Finally, the findings suggest that traditional medium will be completely replaced by digital medium. Design educators must prepare for that change.

Limitations and Future Directions

With the imminent increase of the use of digital media, and its fascinating and compelling use throughout the complete design process, this study provided a baseline to better understand current students' preferences of design mediums. Future studies should address how the design process may be enhanced by using these tools. Moreover, design educators must keep this in mind to better adjust their pedagogical practices to grasp the students' attention and satisfy their needs.

The study was limited by the number of participants. Future studies will be conducted by increasing the sample size. Only two universities mainly focused on industrial design, interior design and apparel design were included in this study. This might have generated some bias in the type of design processes carried out by the participants. Future studies will diversify in the number of institutions and the kind of design programs to select the sample. All data was collected after IRB approval.

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27.1

Audio feedback in distance design education

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Abstract

This paper reports on the use of feedback as part of a tuition strategy applied in a distance design course at The Open University in the United Kingdom. A blended feedback model (audio and summary text) was compared to the existing written-only feedback model in terms of student attainment, use, and perception. Comparison of feedback models confirms findings in the literature around the affective and interpersonal qualities of audio feedback, primarily in developing the relationship between student and tutor in a distance design education setting. The blended model demonstrated no major differences in student assessment outcome but differences in student activity and approach to feedback were observed, specifically that students engage in a series of extended and unexpected feedback opportunities beyond simple models of feedback normally assumed. It is proposed that a blended model, as part of a suite of approaches in a learning design, is more effective than either written or audio alone, allowing far richer student-tutor interactions and outcomes in distance settings.

Keywords

Distance design education, Student-tutor relationship, Feedback, Studio feedback, Feedforward,

Introduction

In design education, the master-apprentice relationship between student and tutor is a historically grounded and signature pedagogy that translated readily to the academy with the professionalisation of design education (Schön, 1987; Cuff, 1992; Shulman, 2005; Sennett, 2008). This paradigm is still very much in evidence today, albeit the authority of the 'master' and associated problems of power imbalances are being recognised and the benefits of a more nuanced relationship emerging (Webster, 2005; Lyon, 2011; I. Mewburn, 2011). More recent explorations of the student-tutor relationship demonstrate the importance of taking a student-centred approach, recognising the co-construction that takes place in positive student-tutor interactions and relationships (Orr et al., 2014; Boling, 2016; Orr & Shreeve, 2018). Research demonstrates that, instead of the tutor acting only as an authoritative expert, better outcomes arise when the tutor uses their expertise to support individual learning through a dialogic approach, where the tutor acts as a 'liminal servant'(Webster, 2004).

In a distance education setting, establishing and maintaining any form of student contact and relationship is a very different challenge (Simpson, 2008; Hill et al., 2009). Hence, how the tutor student relationship noted above is adapted to, and supported in, a distance setting requires particular attention. One key method is through assessment points and using feedback loops as key formative tuition events. Encouraging students to engage with such tuition appropriately, then, has to be supported in ways appropriate to both student needs as well as to the subject studied (Gibbs & Simpson, 2004).

Such approaches in distances education are argued to be similar to dialogic modes of continuous feedback in a traditional design studio setting, relying on the affective qualities of interaction as much as the content (Webster, 2005; I. B. Mewburn, 2009). However, the further challenge of distance is in the loss of such affective qualities, interactions, and events. This paper explores how some of these challenges may be approached in design subjects at a distance and presents a particular method (or blend of methods) of assessment and feedback that demonstrates evidence of affective engagement in assessment and tuition analogous to that seen in traditional studio settings.

Background and context

The Open University (OU) is the largest distance and part time education provider in the UK and offers under- and post-graduate degrees (ordinary and honours) in a range of subject area. The study material is designed to be studied at a distance and divided into courses (modules) of around 60 CATS points (approximately half a traditional university years) each. The OU has an Open Entry Policy with no prior qualification requirements for entry-level study, which leads to a diverse student population when compared to traditional institutions.

This study presents work from the entry level module U101: Design Thinking, which can be studied as part of the BSc / BA in Design and Innovation qualification. This course will typically have between 4-800 students in any presentation and teaching material is provided as online content in a range of media intended to be studied independently. Student tuition and support is provided through tutors responsible for the academic and pastoral support of tutor groups (20 students). Tutors are subject and adult learning experts and their role is to support students' learning both generally and in the subject, hence the relationship is closely analogous to a design education studio tutor in a traditional institution. This relationship is developed through a range of tuition activities: assessment of project work; face to face and online tutorials; online forums; and a virtual design studio. Given the nature of distance education and the importance of the tutor-student relationship in design, these tuition opportunities are critical to student success at the OU.

Assessment feedback

Assessment points in any curricula are critical opportunities for learning and especially through feedback, provided such feedback meets certain conditions. The conditions outlined in Gibbs & Simpson (2004), for example, outline and provide additional detail of expectations and outcomes from assessment that many educators might recognise. Many OU design modules are designed to meet many, if not all, of these conditions and of particular interest for the purposes of this study are:

- (Condition 6) that feedback is timely in terms of next/further learning (or clarification of prior learning);
- (Condition 9) that feedback is attended to (accessed, read, given attention);
- (Condition 10) that feedback is acted on (that actions and behaviours changes in response to feedback).

The primary vehicle for assessment are design projects (appropriate to level and stage of study), which are used summatively for assessment and formatively to provide tuition feedback. This combination of summative and formative feedback is the main means of providing tuition to students on many modules. Students submit project assessments using CompendiumDS, software designed for use in OU design courses. This allows students to present their work and design process spatially using a range of media and text (Figure 1), giving them a freedom of expression important in articulating incomplete ideas or design steps. A key focus of assessment in design at the OU is the design process as opposed to the final design output, allowing tutors to 'see' students' thinking and support its development (Jones, 2014).

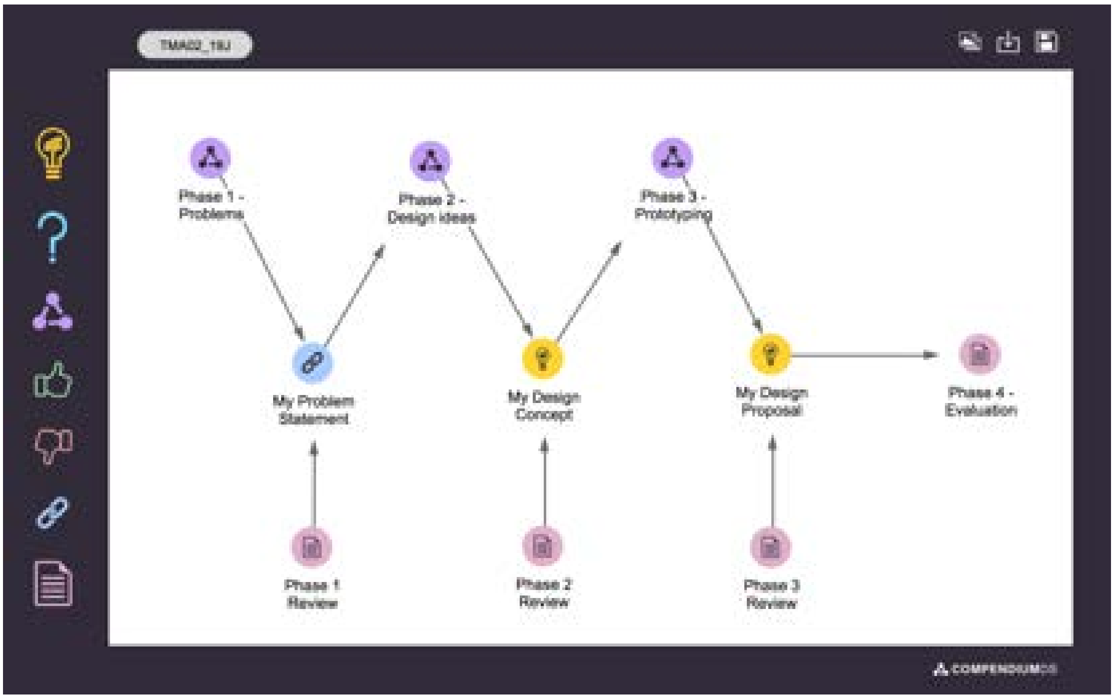


Figure 1 CompendiumDS concept mapping software showing a blank assessment template.

Students submit their work, referred to as a Tutor Marked Assessment (TMA), through an online assessment system. Tutors download and assess students' work and provide detailed feedback embedded in the CompendiumDS file, returning this to the student via the same online assessment system to complete the feedback loop.

The main motivation for the study was a concern that students were not using feedback as intended, an issue reported elsewhere (Cann, 2014). Specifically, returning to Gibbs and Simpson, it was felt that students were neither attending to feedback (looking at it, reading it, accessing it) or acting on it (changing behaviours, actions, etc. in response to feedback), both key conditions in the latter stages of the complete feedback cycle outlined in Gibbs & Simpson (2004). Here, the feedback definition of identifying the gap between the 'actual and reference levels' (Ramaprasad, 1983) is important but with the critical addition of "…when it's used to alter the gap" (Sadler, 1989), particularly relevant to design subjects.

Personal connection and presence

Creating and generating ideas in a design process is a very personal act and exposing these ideas to scrutiny and criticism can be particularly challenging for novice designers. Hence, feedback cannot simply focus only on content alone; it must also consider the ways in which it is received and its effect. Feedback that alienates or discourages students to engage with criticism is less likely to be used, hence, how feedback is 'performed' is important.

Studies show that audio feedback can be perceived as more emotionally engaging by students when compared to other modes (Crook et al., 2012), and its contribution to pastoral support is well documented (Dixon, 2015). This happens through the communication of metalinguistic elements that are hard to reproduce in purely written modes, making the feedback feel more personal to the student (Cavanaugh & Song, 2014; Parkes & Fletcher, 2014). This can lead to perceptions of audio feedback as being easier to understand (Merry & Orsmond, 2008) and hence have a positive academic effect (Ice et al., 2007). Making use of such metalinguistics enables design tutors to be critical of student work whilst mediating this criticism emotionally and affectively (Woodcock, 2017).

Studies have also demonstrated that audio is an effective medium to project presence at a distance (Ice et al., 2007), albeit not all studies agree fully with these findings, arguing that more work in this area is required (Borup et al., 2014). Presence, how we project ourselves using extrinsic media, such as online and distance learning environments (Short et al., 1976; Munro, 1991), and can be applied usefully as a concept in distance education to improve learning outcomes for students (Munro, 1991; Armellini & De Stefani, 2016; Shin, 2002). Hence, a secondary motivation for the study was the idea that audio feedback could further improve and enhance the student-tutor relationships, possibly through presence considered pragmatically rather than formally.

Time and quality

One challenge in providing high quality tuition feedback is the time required to create it (Cavanaugh & Song, 2014). In a distance context this is often more difficult because the tutor and student may never meet face to face, hence affective and personalised feedback has to be created with little or no relationship established. At a practical level, very careful language has to be used in written feedback, sometimes resulting in long or awkward phrases required to maintain a balance between critical assessment and student motivation (Walker, 2009). Providing this type of written feedback is considered a core competency in OU tutors.

In the OU context, the time it takes to create written feedback is generally high for the reason just outline but also because assessment feedback at a distance is (usually) the primary tuition mode. Although some studies suggest that audio feedback takes longer than written feedback (Parkes & Fletcher, 2014), other studies report it as quicker or about the same time (Ice et al., 2007; Rotheram, 2009). Hence, the issue of time was a third major motivation for trialling audio feedback.

The issue of quality of audio feedback is important to consider because it does take practise and skill to record and provide the type of verbal feedback desired. Similarly, not all tutors (or students) wish to record audio for a range of reasons. At a practical level, having the right equipment, training and environment within which to record audio can also be relevant factors. Hence, the audio trial reported here was carried out on an entirely voluntary basis by tutors wishing to try the format. That said, the context of feedback matters and can significantly influence perceptions of quality. In a studio setting, verbal feedback in a tuition setting is the norm and is rarely recorded in any way. Translating to a distance setting almost always requires some artefact of communication for feedback (text, audio file, notes, etc.), meaning that it is very often treated differently to a conversation, regardless of how it is intended. Creating the right balance between informal and formal content and tone can be important to ensure perceptions of quality and confidence in the feedback relationship.

Research aims and questions

The motivations identified above led to an early trial in 2016 to test audio feedback in a single tutor group. This identified that a blended feedback model (audio and summary text): significantly reduced the amount of time required to create feedback; provided a feedback quality that was at least as good (if not better) than the written equivalent; and allowed the presentation of very critical feedback points that were still perceived to be friendly, personal, and supportive.

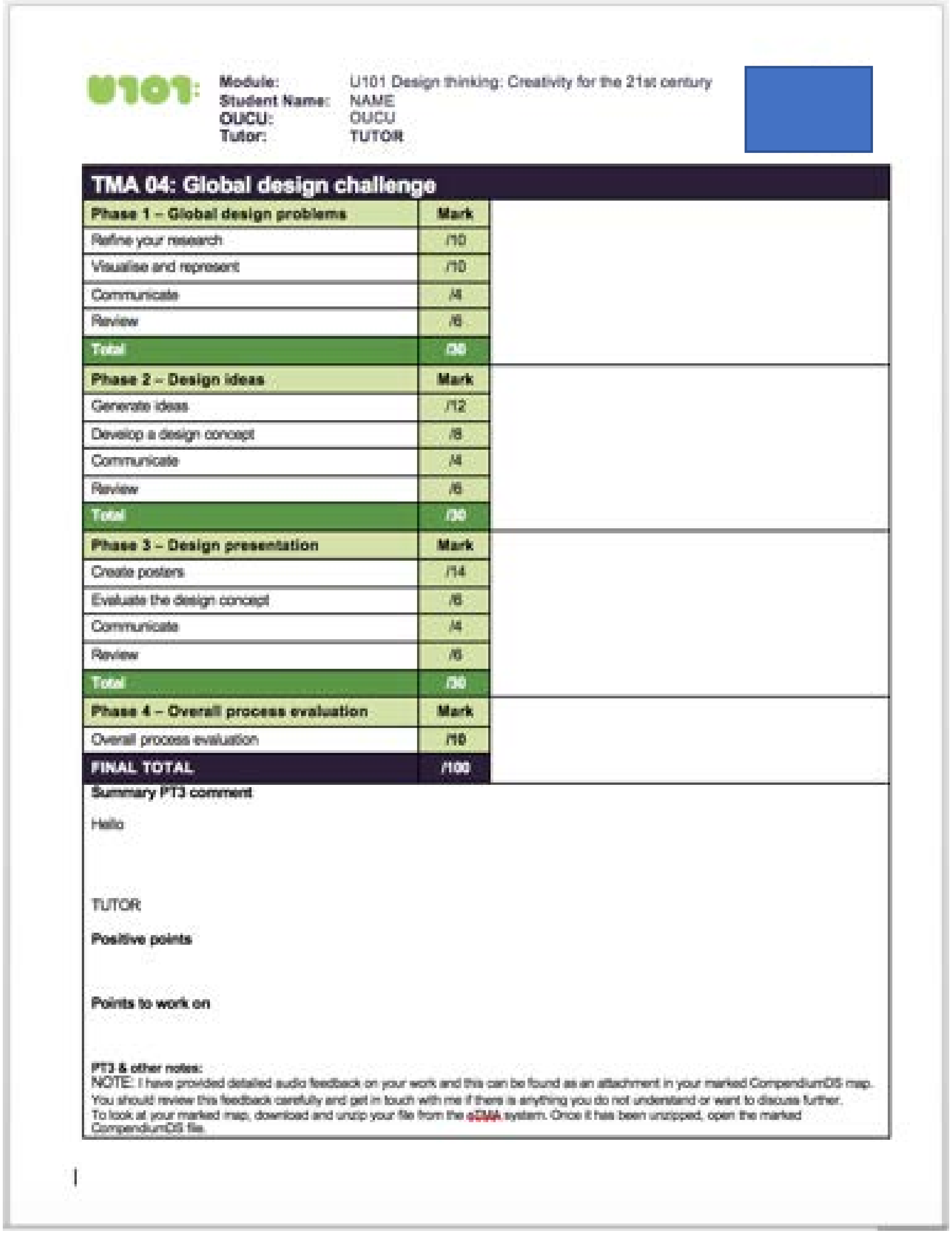
Following this, a larger trial (reported here) was designed to verify these initial findings, compare them to existing written only feedback modes, and respond to the following research questions:

- Are there significant differences in student attainment between written only and blended feedback modes?
- Are students making use of feedback and, if so, in what ways?
- What are student perceptions (positive and negative) of feedback and, in particular, critical feedback? Are they able to recognise the value of the feedback process in itself?

Method

Study setup

The study involved a comparison of two groups: written-only feedback and blended feedback. Students in both groups undertook identical assessment tasks, submitted these using CompendiumDS, and were assessed using identical course criteria by their respective tutors. Both groups received a standard (OU system) summary feedback form, containing their marks and summary plain text outlining overview feedback and feedforward points only. Students in both groups also received a returned CompendiumDS map containing feedback. The returned feedback varied by group: the written-only feedback group received a text document with detailed, written feedback; the blended feedback group received recorded audio feedback (MP3 digital file) and written summary feedback using a standard proforma sheet aligned to the marking scheme (Figure 2).



U101:

Module: U101 Design thinking: Creativity for the 21st century
Student Name: NAME
OUCU: OUCU
Tutor: TUTOR

TMA 04: Global design challenge		
Phase 1 – Global design problems	**Mark**	
Refine your research	/10	
Visualise and represent	/10	
Communicate	/4	
Review	/6	
Total	**/30**	
Phase 2 – Design ideas	**Mark**	
Generate ideas	/12	
Develop a design concept	/8	
Communicate	/4	
Review	/6	
Total	**/30**	
Phase 3 – Design presentation	**Mark**	
Create posters	/14	
Evaluate the design concept	/6	
Communicate	/4	
Review	/6	
Total	**/30**	
Phase 4 – Overall process evaluation	**Mark**	
Overall process evaluation	/10	
FINAL TOTAL	**/100**	

Summary PT3 comment

Hello

TUTOR

Positive points

Points to work on

PT3 & other notes:
NOTE: I have provided detailed audio feedback on your work and this can be found as an attachment in your marked CompendiumDS map. You should review this feedback carefully and get in touch with me if there is anything you do not understand or want to discuss further. To look at your marked map, download and unzip your file from the eTMA system. Once it has been unzipped, open the marked CompendiumDS file.

Figure 2 A blank summary feedback document used as part of the blended feedback.

The study sample comprised 26 tutor groups: 21 of which received written-only feedback, 5 of which received blended feedback. Both groups were informed they would receive feedback, the format it would take, and guidance on how to use it (all part of normal tutor practice).

Monitoring quality of assessment and feedback took place using standard processes: 1) statistical analyses and monitoring of all tutor assessment during the course; 2) randomly selected samples of assessments regularly evaluated by the course team; 3) end of course assessment panel with peer and external review. No negative quality issues (quantitative or qualitative) were identified arising from the study.

Student survey

Students were invited to complete an online survey to investigate perceptions of feedback. The survey was divided into four sections around: general engagement; students' responses; student activity; and general (open) comments. The survey questions adapted according to sample group (written or blended). Draft questions were iterated in consultation with institutional survey experts as part of the approval processes. Questions using statement agreement utilised a Likert scale of Strongly Disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree. The full set of questions can be found in the open data repository (https://doi.org/10.21954/ou.rd.9699236).

Towards the end of the course the entire student cohort (315 students) was invited by email to complete the survey with no difference in targeting of either group. 68 students responded (21.6% response rate), providing final survey samples of 17 students from the blended feedback group, and 52 students from the written-only feedback group, 25% and 75% of the responding sample, respectively.

The samples contain two potential biases. Firstly, being at the end of the course, the sample reflects students who were close to completing, hence students who withdrew are not represented in the study. Secondly, there may exist a 'self-selection' bias in terms of students particularly motivated to respond for particular reasons. These two biases are, however, general to distance education and the OU context and are not study-specific biases.

Descriptive statistics were used to summarise and analyse responses to multiple choice questions. Thematic analysis (Braun & Clarke, 2006) of the open text responses was carried out and coded using NVivo. A generally constructivist grounded approach to theme identification was undertaken (Charmaz, 2000) but, given the subject area, strong latent themes were quickly identified. In addition to latent themes, valence themes were also coded to include positive/negative responses. This provided a consistent coding structure of structured nodes and sub-nodes. The full set of codes and results can be found in the dataset available here: https://doi.org/10.21954/ou.rd.9699236

Results and discussion

Student attainment

Analysis of assessment results revealed no statistically significant differences between groups. The overall average cohort assessment mark was 77.1% (sd = 14.8%) and all blended feedback tutors were within one standard deviation of this and distributed throughout the overall tutor group (Figure 3).

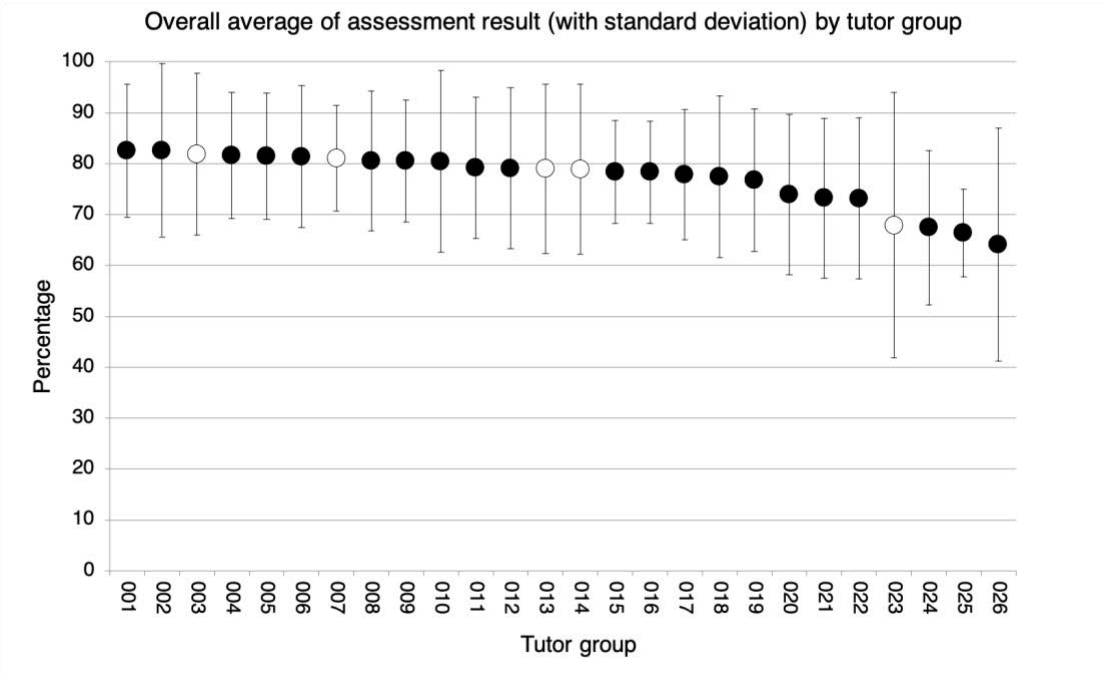


Figure 3 Overall Average assessment results and Standard Deviation awarded by tutor group. Blended tutor groups in white.

Question 02 asked about difficulties students may have had accessing (technically) feedback, and the majority of responses were, surprisingly, with the written-only feedback group: 11.5% of students reporting difficulties compared to only 5.9% in the blended feedback group. In all cases, the problems provided in the open response (Question 03) identified difficulties with institutional and online systems and tools, not the feedback mode or material itself. Technical issues around audio files and players reported in other studies (e.g. (Merry & Orsmond, 2008; Rotheram, 2009)) were not observed. This may be due to way audio is handled technically and presented to students as a directly and easily playable file in CompendiumDS, effectively removing any technical requirements or additional software. No students in either group reported difficulties in reading or understanding feedback (Question 04).

Overall, and responding to Research Question 1, the results confirm that student groups receiving blended feedback achieved similar academic outcomes to students receiving written-only feedback. No specific or persistent issues of accessing and understanding the material were reported in either group.

How feedback was used

Students reported high levels of engagement with all feedback modes and no students claimed to ignore the feedback for all assessments (Table 1). Audio feedback shows slightly less engagement in terms of reported use when compared to written only but this seems to be contradicted slightly when asked about the number of times the audio was listened to (Table 2), possibly suggesting a different pattern of use in this group.

Table 1 Question 01: After how many of your TMAs did you [read/listen to/read] this feedback?

Question 01	Written only	Blended	
		Audio	Summary
All	60 (96.2%)	13 (76.5%)	17 (100%)
More than half	2 (3.8%)	4 (23.5%)	0
None	0	0	0

Table 2 Question 06: On average, how many times did you [read/listen to] the [written/audio/summary] feedback.? (Please select one only)

Question 06	Written only	Blended	
		Audio	Summary
Once	5 (9.6%)	5 (29.4%)	7 (41.2%)
Twice	24 (46.2%)	7 (41.2%)	6 (35.3%)
Three times	9 (17.3%)	2 (11.8%)	2 (11.8%)
More than 3 times	13 (25%)	2 (11.8%)	1 (5.9%)
Not sure	1 (2%)	1 (5.9%)	1 (5.9%)

Questions 18-22 asked about specific activities students engaged in using feedback (Table 3). This shows a generally high self-reported engagement level with feedback in both groups, going beyond simply looking at marks.

Table 3 Questions 18-22 "When [reading/listening to] the feedback did you:" (respondents who selected 'yes').

Question		Written only	Blended	
			Audio	Summary
18	Look at the CompendiumDS assignment to which it related.	49 (96.1%)	12 (70.6%)	12 (70.6%)
19	Take notes.	20 (38.5%)	8 (47.1%)	5 (29.4%)
20	Share feedback with other students.	5 (9.8%)	1 (5.9%)	1 (5.9%)
21	Read all the comments.	50 (98.0%)	17 (100%)	17 (100%)
22	Read only parts of the [Feedback/Summary sheet] (and skip the rest).	0	0	0

Students using written-only feedback were more likely to look at the work they submitted compared to the blended feedback group. One of the original ideas behind the blended feedback model was that students might more frequently use the audio to listen whilst also looking at their work. This was not supported by the results, at least in the way it was assumed to take place. The 'simple' feedback model imagines a student attending to the feedback immediately, relating it to their work, reflecting on the differences, and remembering this for future use: a linear model of feedback. But the actual behaviours reported by students were more complex and nuanced than this suggests.

Firstly, there was evidence that some students do respond to feedback using both written only and blended feedback models:

> *"When read in conjunction with the compendium DS Mark they helped me to understand where I lost points and how I could improve on my next assignment."*

> *"Gives a good idea where you could improve and gives ideas of what you may have missed out."*

Both examples here show a clear recognition of the value of a simplified feedback, identifying differences between 'actual and reference levels' (Ramaprasad, 1983) and then extending this to how it can make a difference to future work, i.e. feedback used to 'alter the gap' (Sadler, 1989). Hence, both the mechanism and value of feedback is recognised by some students.

Secondly, there was some evidence of students engaging in reflection between feedback elements and events:

> *"Having a copy of the written feedback in front of me helped me to jump between different parts when reviewing my work."*

> *"It was good to reinforce the verbal appraisal with the written [summary] one."*

In addition, students using blended feedback were also more likely to take notes compared to students with written feedback (Table 3). The possibility here is that audio, rather than reading, seems to be preferred for notetaking.

Thirdly, there was evidence that students considered feedback and then related this to their work independently (i.e. did not use the feedback and refer to their work directly at the same point in time):

> *"I didn't need to look at compendium because it was obvious which parts of it related to although I looked through afterwards just to be sure."*

> *"Afterwards I checked the work it was related to. The TMA is what small enough for me to be able to know which assignments the tutor was referring to."*

This was an unexpected result and it perhaps highlights the differences between a theoretical view of how students should use feedback and what they actually do. At the OU, many students are very 'time poor', often studying at the same as having a number of other commitments. Hence, approaches such as this may well be a time-effect method of studying, albeit that may come with some 'learning risks'. Further work is needed to understand whether such strategies are effective for students, what their effects might be, and whether they can (or should) be explicitly supported using methods such as that reported.

Fourthly, students were clearly aware of feedforward: where feedback is deliberately articulated to change future work or outcomes by specifically identifying what will be expected next (Race, 2005; Brearley & Cullen, 2012). This form of feedback is used explicitly in design tuition feedback and the number of open text responses that referred to it (33 in total) suggests that students recognise this as well as its value in their personal development:

"The pointers on how I would have gained more points and how in the future I could gain more point [were most useful]; this is included improvements on my photographs, written work, etc."

Finally, a further asynchronous use of feedback was identified by a number of students who made use of feedback at different times during the course. The use of previous feedback at the end of a course was to be expected and students did report making good use of this application of feedback:

"When I was putting together my portfolio in my final assessment I listened to the feedback over and over. This helped me focus on my weak points and improve on stronger points."

"My tutor not only discussed the TMA, but also give me helpful advice for the EMA. Reading the feedback for my TMAs give me a much clearer idea of how to tackle the EMA."

But students also reported using this mechanism between assessments and clearly recognised the value of this as a continuous feedback mechanism operating continuously as part of their learning process.

"The feedback built on and referred to previous TMAs which added to a sense of continuity which was useful as each assignment was so different."

"Feedback helps to find out my week and stronger areas so I can focus on areas for improvement. I note it down a few comments which I could refer to in my EMA essay, especially relating to learning outcomes and whether I met them on my first assignment feedback."

In response to the second research question, students do make use of feedback and they do so in a number of different ways. Asking whether or not students 'read feedback' is perhaps too simplistic when considering the value and purpose of feedback as part of learning. The five ways of using and interacting with feedback outlined above clearly demonstrate a more nuanced and varied approach by students than is often presented in traditional feedback theory.

Student perception

Results from the fixed response survey questions 08-17 focused on student perceptions of feedback (Table 4). The high levels of agreement demonstrate a perception of high-quality feedback by students regardless of mode, once again highlighting the importance of feedback quality as part of assessment.

Table 4 Percentage of students who Strongly Agreed or Agreed with the statement "The [audio/written] feedback…"

Question		Written only	Blended	
			Audio	Summary
08	…explained why I got the grades I did	94%	94%	82%
09	…helped me to learn and to understand the subject better	90%	71%	65%
10	…told me how I could improve in future work	90%	94%	88%
11	…helped me with future assignments and examination	90%	82%	88%
12	…was clear and easy to follow	94%	88%	94%
13	…was detailed	84%	88%	82%
14	…I received was enough	82%	94%	82%
15	…was personal to me	88%	94%	94%
16	…was motivating	84%	82%	94%
17	…was presented well	90%	88%	100%

Open comment analysis

Questions 25 and 26 allowed open comments on what students found most useful and how feedback could be improved respectively, and question 27 allowed an 'any other comments' open response. Analysis of open comments revealed an overwhelmingly positive response to both written and audio feedback with 66 references having a positive valence compared to only 2 with a negative valence. The full coding list is available here https://doi.org/10.21954/ou.rd.969923 and visualised in Figure 4.

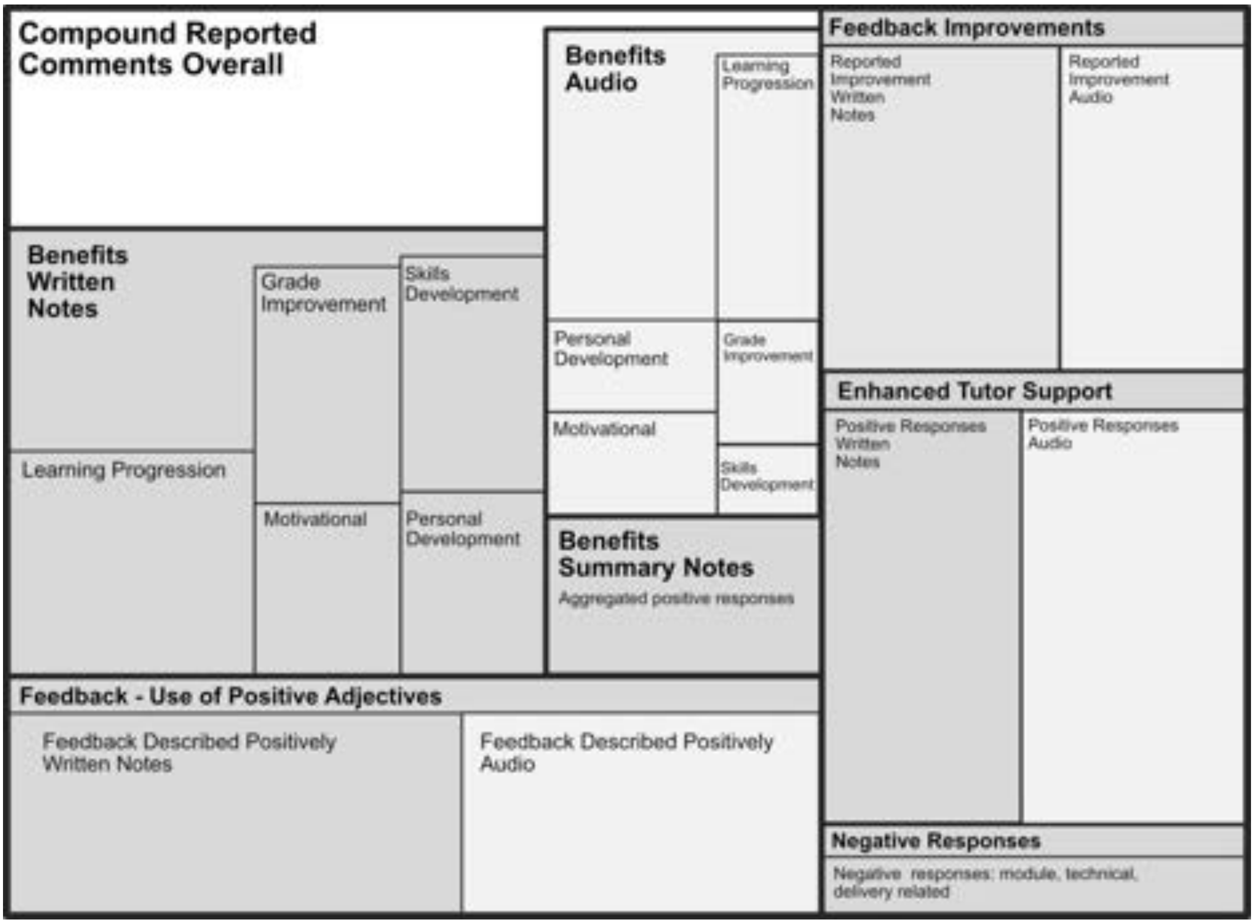


Figure 4: Hierarchy chart showing student reported feedback perceptions of written and audio feedback.

What Figure 4 reveals is that students are able to articulate details about feedback as they relate to their learning. As an example, Table 5 summarises the coding counts for perceived benefits (192 in total).

The significance of these results is not in the numbers themselves but in the qualitative nuance of responses, indicating a range of student-perceived benefits not simply limited to behavioural or transactional outcomes. For example, developing responses to critical feedback is important in design and how this is achieved, as noted previously, can be challenging. The results here suggest that the audio feedback allows critical design feedback to be made in a way that ameliorates the negative perceptions that can accompany criticism:

> *"I also felt the feedback felt less critical and more motivational than written can sometimes feel. You have addition of the tone of the tutors voice to help convey the message."*

> *"Felt a more personal, honest feedback."*

What is revealing is that students also recognise this and, going further, link it to factors that relate to successful learning, such as motivation:

"For instance written feedback can potentially seem quite negative but with an enthusiastic and kind voice behind it, it can be more motivating can seem more constructive."

"The tutor was enthusiastic and that's helped hugely with my motivation."

Or confidence:

"The feedback I received give me confidence in my ability and confirmed that I had approached the assignment in the correct manner."

The critical point here is to note both the students' perception of effect and the awareness of effect. The first is useful enough but the latter demonstrates a relationship of trust between student and tutor as well as developing aspects of self-learning and agency.

Table 5 Analysis of open text responses: Number of coded instances for Feedback Benefits

Code (and sub-codes)	**Description**	**Files**	**References**
Feedback benefits overall (blended)	Combined responses of audio and written feedback that cite particular feedback mechanism benefits.	5	192
Benefit - audio	Overarching sub-category of cited benefits of audio feedback.	4	48
grade improvement	Cited benefit - improvement of grade - audio	1	4
learning progression	Cited benefit - contribution to learning progression- audio	3	9
motivational	Cited benefit - pastoral/motivational encouragement - audio	2	7
personal development	Cited benefit - contributes to personal development - audio	2	7
skills development	Cited benefit - contribution to skills development - audio	1	2
Benefit - written	Overarching sub-category of cited benefits of written feedback.	5	89
grade improvement	Cited benefit - improvement of grade - written	3	14
learning progression	Cited benefit - contribution to learning progression- written	4	23
motivational	Cited benefit - pastoral/motivational encouragement - written	3	11
personal development	Cited benefit - contributes to personal development - written	2	9
skills development	Cited benefit - contribution to skills development - written	3	13
Benefit - summary	Responses that are essentially summaries of benefit value of written feedback.	2	15

The significance of these results is not in the numbers themselves but in the qualitative nuance of responses, indicating a range of student-perceived benefits not simply limited to behavioural or transactional outcomes. For example, developing responses to critical feedback is important in design and how this is achieved, as noted previously, can be challenging. The results here suggest that the audio feedback allows critical design feedback to be made in a way that ameliorates the negative perceptions that can accompany criticism:

> *"I also felt the feedback felt less critical and more motivational than written can sometimes feel. You have addition of the tone of the tutors voice to help convey the message."*

> *"Felt a more personal, honest feedback."*

What is revealing is that students also recognise this and, going further, link it to factors that relate to successful learning, such as motivation:

> *"For instance written feedback can potentially seem quite negative but with an enthusiastic and kind voice behind it, it can be more motivating can seem more constructive."*

> *"The tutor was enthusiastic and that's helped hugely with my motivation."*

Or confidence:

> *"The feedback I received give me confidence in my ability and confirmed that I had approached the assignment in the correct manner."*

The critical point here is to note both the students' perception of effect and the awareness of effect. The first is useful enough but the latter demonstrates a relationship of trust between student and tutor as well as developing aspects of self-learning and agency.

In a design context, the trust developed through the student-tutor relationship is, as noted previously, critical and its value is also clearly evident to students evidenced in unsolicited comments (Table 6).

Table 6 Analysis of open text responses: Number of coded instances for 'Tutor support'

Code (and sub-codes)	Description	Files	References
Tutor support	Responses that specifically refer to quality of tutor support or tutor/student relationship.	3	34
Tutor support negative	Responses that are specifically focused on some negative aspect[s] of the tutor/student relationship.	2	2
Tutor support positive	Responses that are specifically focused on some positive aspect[s] of the tutor/student relationship.	2	32

In a traditional setting the tutor-student relationship depends on physical, synchronous interaction which is an obvious challenge at a distance. Expressing and signalling presence can ameliorate such issues of isolation and improve learning at a distance (Gunawardena & Zittle, 1997), and it is through elements and interactions such as feedback that it can be signalled (Munro, 1991; Armellini & De Stefani, 2016). It can also be signalled through audio feedback (Ice et al., 2007) and the open comments suggest some recognition of this, particularly in social and interpersonal terms difference :

> *"I enjoyed the feeling of a personal connection with my tutor."*

> *"It was good to hear a human voice explaining things. Much better than written feedback."*

Again, how this translates to developing a learning relationship as well as an awareness of this is what is particularly interesting. For example:

> *"I think the most useful aspect of feedback is tutors pickup on things that students are not aware of doing. Little bad habits as in my case."*

In the comment above, the student could be argued to be indicating their presence through a personal characteristic (habits), that they know their tutor also knows about this (relationship), as well as how that is useful to them as a learner (to identify things they were unaware of and improve them).

Finally, there is some evidence of awareness of, or even developing, the more subject-specific form of design identity, a critical part of the overall learning journey in design (Cross, 2004) and something just as important in a distance context (Lanig, 2019). This has been linked to the idea of 'design presence' in some studies (Jones et al., 2020). In this early course, as expected, students perceive their tutor to exhibit such a domain-specific identity:

> *"My tutor showed good examples of work which helped me to produce better quality outcomes."*

> *"It is important to link the comments with the work especially if it [is] regarding images. It is good to look at the images as if I was sitting with my tutor."*

What is unclear was whether this informed students' own design presence in any way and a future direction of inquiry would be to test this, particularly at more advanced levels of learning.

Negative responses

The number of negative comments was small compared to the number of positive responses. The majority of negative comments (7 of 10) were not directly related to feedback issues but to aspects of the course itself, its delivery mode (online), or other specific and personal matters (Table 7).

Table 7 Analysis of open text responses: Number of coded instances for 'Negative experience'

Code (and sub-codes)	Description	Files	References
Negative experience	Overarching category that cites a range of negative experiences	5	10
negative feedback online VLE		2	2
negative feedback OU environment-related		1	1
negative feedback-related	Negative comments that are specifically critical of aspects of feedback	2	3
negative module-related	Negative comments focused on module itself	2	3
negative tutor-related	Negative comments that directly relate to the tutor.	1	1

There were only two recorded instances of contextually negative commenting on feedback. Even so, one of these (from a professional sound engineer) was not critical of audio feedback in itself, but rather the technical recording quality of the audio feedback:

> *"As a recording engineer I prefer to be more professionally recorded. I just find whole recordings are little poor in general. We try and take good quality photos and write English well but we don't seem to care about audio recordings… not yet"*

This comment, like many others, assumes the effectiveness of the blended model and seeks to improve it, a position reflected by other student comments around future improvements, such as: expanding to video feedback; including audio bookmarking features; or to simply have more of it.

Summary

Blended is best

The finding that blended feedback was used in student revision and personal reviews of work is offered as a solution to the problem of audio-only being problematic (Woodcock, 2017; Rasi & Vuojärvi, 2018). This study demonstrates that using audio as part of a blended approach, has the greatest potential to improve feedback, supporting findings elsewhere (Carruthers et al., 2014; Rasi & Vuojärvi, 2018). The unfortunate framing of audio as an 'either-or' choice of feedback mode is argued to be problematic in that it simplifies what is a complex learning practice.

Taking a blended approach moves beyond a simplistic model and responds to other critical issues around using media in too narrow or too broad a sense. For example, using audio only can make it difficult to use as feedback because of the linear nature of the media (Parkes & Fletcher, 2014), but by having both audio and summary, the feedback can operate at both 'timescales'. Conversely, providing a range of media does not necessarily offer the types and flexibility of choice students require for effective learning habits (Mandernach, 2009), hence, by providing a limited, but effective, choice of feedback a more targeted and resource-effective approach can be taken.

The blended model offers a greater range of options for personal study, combining the known benefits of audio feedback with newly identified habits of learning and feedback use. Providing choice increases the chances of feedback being used; improves students' ability to amend the feedback gap; and develops student learning competencies and attitudes.

Reflection, feedback and feedforward

The choice available in blended feedback is not only limited to mode, but also to when (and how) feedback is used. Immediate student use of audio serves to positively reinforce affective aspects of learning (connection, presence, confidence, etc.), whilst later reflective use, especially of the summary text, serves to close the feedback loop when engaging in the next assessment task.

To support this, feedforward is argued to be as important as feedback, particularly in a subject such as design where past processes are easily projected to future actions. This is argued to be the critical component of this feedback model and where it has the greatest potential to 'alter the gap (Sadler, 1989). When this feedforward is reinforced in assessment feedback, longer loops of continuous feedback emerge between assessment points which, in turn, become routine in student behaviour. Again, it is the blend of both immediate and longer-term reflection that is argued to be of greatest benefit to students.

Critical but supportive

Many studies have linked the affective and personal properties associated with audio feedback and this study confirms many of these. But what is also demonstrated here are the links between these and student development (not just learning), as well as students' ability to consciously recognise and value these properties. Student capacities and attitudes matter just as much as skills or actions in design education (Kimbell & Stables, 2007), a fact that can be difficult to communicate to novice designers. By signalling this importance through the critique and feedback process students are able to make such realisations for themselves. As with the previous points, it is the blend of both critical and supportive commentary that seems most effective – in other words, the operational affordances of an instructional act (such as the summary feedback sheets) in combination with the affective properties of the tuition act (the audio feedback delivered conversationally).

In summary, the results outline positive differences in affect, preference, and perception of a blended mode of feedback and as part of a wider provision of high-quality feedback in a continuous process. It is fair to conclude that there are no single best approaches to suit all students in all conditions, but strong evidence is presented to support subtle differences in practice that support better tuition practices under particular conditions and that address issues identified in previous studies. Taking both a student-centred and subject-oriented approach to the blends of modes of feedback offered is argued to be more valuable than asking whether one or the other is better. Most importantly, it is possibly the recognition of this by students in developing their own learning practices that is the most effective indicator of success.

Statement on open data and ethics

The survey questions, text coding, and quantitative results data from the survey are available here: DOI: 10.21954/ou.rd.9699236

All survey data was collected using (Anonymised) institutional procedures and systems that deal with student permissions, ethics, declarations, and use of student data.

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Appendix A: Adaptive survey questions and structure

Part 1

The first set of questions asked a series of direct questions with different response types appropriate to the question. Students in the blended feedback group were asked a similar question for both the audio and summary feedback elements.

No	Written feedback	Responses
01	[written] Your tutor provided written feedback on your TMA. After how many of your TMAs did you read this feedback? [audio] Your tutor recorded verbal feedback on your TMA in a spoken message. After how many of your TMAs did you listen to this feedback? [summary] Your tutor provided written feedback on your TMA by completing a feedback summary sheet. This showed your mark and key points. After how many of your tear is did you read this feedback?	All More than half None
02	Did you have difficulties in accessing the [written/audio/summary] feedback?	Yes / no
03	Please explain why you had difficulty accessing the [written/audio/summary] feedback.	(open text box response)

04	When you accessed the feedback, did you have any difficulties in reading or understanding it?	Yes / no
05	[If 04 was yes] Please explain why you had difficulty [reading/listening to] the [written/audio/summary] feedback.	Open text entry box
06	On average, how many times did you [read/listen to] the [written/audio/summary] feedback.? (Please select one only)	Once Twice Three times More than 3 times Not sure
07	On what device(s) did you [read/listen to] the [written/audio/summary] feedback from your tutor? (Please select all that apply)	Desktop computer Laptop computer Tablet Smartphone e-reader Other (Not applicable

Part 2

Part 2 contained 10 multiple choice questions (Questions 08 – 17), using the following response choices:

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Each question was preceded by the text: “To what extent do you agree, or disagree, with the following statements about the [written/audio/summary] feedback you received from your tutor? (Please select one answer in each row)”

No	**Written only**
08	The feedback explained why I got the grades I did.
09	The feedback helps me to learn on to understand the subject better.
10	The feedback told me how I could improve in future units.
11	The feedback helped me with future assignments and examination.
12	The feedback was clear and easy to follow.
13	The feedback was detailed.
14	The amount of feedback I received was enough.
15	The feedback was personal to me.
16	The feedback was motivating.
17	The feedback was well presented.

Part 3

The following questions were asked as a list of questions with response options

- Yes
- No
- Not applicable

Each question was preceded by the text “When [reading/listening to] the feedback did you:”

No	Question
18	[Look at / Listen to] the CompendiumDS assignment to which it related.
19	Take notes.
20	Share feedback with other students.
21	Read all the comments.
22	Read only parts of the [Feedback/Summary sheet] (and skip the rest).

This section ended with open text entry boxes response for the following questions:

No	Question
23	Please briefly explain if and why you found doing this/these beneficial.
24	[Conditional on Q 21] On the Last page you said you only read parts of the [written/summary] feedback. Why did you not read all of the written feedback from your tutor?

Part 4

The final section used open entry text boxes to solicit responses to general questions, as follows:

No	Question
25	What did you find most useful about the [written/audio/summary] feedback?
26	In what ways could we improve the feedback.
27	At the start of the questionnaire you say that you did not read any of the [written/audio/summary] feedback. Was there a reason you decided not to?
28	Do you have any other comments about the feedback and tutor support provided in U101?

Exploratory study on the role of institutional frameworks on engineering curricula evolution: A case study on transition towards sustainability

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Abstract
Humanity's entrance into the Anthropocene forces us to question the role of technology because of its impacts on the environment. The stake is the viability of the Earth system for humans. Engineers producing a large part of these impacting techniques are not trained in sustainable issues (environmental, social and economic ones - in a systemic way). An exploratory workshop was held at a French University of Technology to study the development of new engineering training courses on issues of strong sustainability. During this workshop, the participants were placed into the current French institutional framework and were asked to develop a new training within this specific framework. The hypothesis formulated at the end of this experiment is that current institutional frameworks can be an obstacle to the production of new training, especially training adapted to the transition phenomenon to respond to the increasing risk of socio-ecological catastrophes. This experiment was conducted as part of a heuristic approach and opens up new perspectives for the evolution of training as well as institutional frameworks in higher education and research.

Keywords
Ecological catastrophes, engineering studies, education, institutional framework

Introduction
The entrance of humanity into the Anthropocene (Steffen et al., 2015) requires us to rethink technology by considering the impacts technical tools have on the ecosystems. All these techniques used by man (our activities in a broader sense) and their impacts can be understood as the anthroposphere. This anthroposphere is in constant exchange with the biosphere, which is defined by all ecosystems and living organisms evolving in their living environments. These two spheres interact: our industries draw their raw materials from the biosphere to meet all of society's needs (basic and non-basic needs). This interaction seems one-sided. Indeed, the impact of the anthroposphere on the biosphere is such that the latter is struggling to recover. Indeed, each year, the rate of resource extraction exceeds that of resource regeneration (especially fossil ones), while the quantity of emissions exceeds that which the biosphere is capable of absorbing to sustainably ensure our living conditions (especially a stable climate). In other words, the current metabolism of the anthroposphere in the biosphere is unsustainable and compromises the viability of the earth system (Court & Fizaine, 2017; Meadows et al., 1972), at least the continuity of current human productive activities.

The models in the Limits to growth report for the period 1970 – 2000 have been verified (Branderhorst, 2020) and the projections made in the 1972 report are in strong agreement with the historical data (again for the period between 1970 and 2000). It appears that the projections in this report also conclude that there is a possibility of a global collapse before the end of the mid-21st century. « The salient message from the [Limits to Growth] modelling was that continued growth in the global economy would lead to planetary limits being exceeded sometime in the 21st century, most likely resulting in the collapse of the population and economic system, but also that collapse could be avoided with a combination of early changes in behaviour, policy, and technology.” (Turner, 2008). In this article we are focusing on those possible changes, and more precisely changes related to technology: how to change technology design by the education of future designers? This paper will take a narrow understanding of design, as we will address engineering design only and engineering education in the French context.

One possible change is to integrate sustainability issues into engineering curricula. Engineers apply "scientific principles to solve problems to improve society. Engineering is a service profession. However, day-to-day engineering is more often focused on technological rather than human concerns" (Chan, Eng, & Fishbein, 2009). The training of engineers in environmental and social issues is therefore essential to develop technologies that respond to societal challenges (Chan et al., 2009) and to make the interaction between anthroposphere and biosphere sustainable. The integration of environmental issues in engineering curricula is not a new thing. Through the 20th century until now, engineering education to sustainability has considerably changed, starting from a very material and environmental-oriented approach to a more holistic understanding of sustainability issues (integrating social issues and multi-scales issues, ethics) (Quist et al., 2006; De Graaff & Ravesteijn, 2001). Nonetheless, this holistic understanding of sustainability is quite a challenge to integrate into current engineering curricula. In 2010, a call to “study engineering in the context of service to society and the need to address complex challenges to the 21st century” (Grasso & Burkins, 2010) asserts that the framework for engineering education is fragmented into disciplines. However, the challenges of the 21st century are multi-dimensional (cultural, political, social, environmental) and it is difficult – unrealistic would be probably more appropriate – to grasp the issues without solid knowledge in other fields. Even, a lot of literature express the need for engineers to develop other competences and other mindset (De Graaff & Ravesteijn 2001; Hsiao 2019; Quist et al. 2006; Vare & Scott, 2007). As said by James Pitt, “advances in the STEM domains of science, technology, engineering and mathematics have given us both the capacity for causing such degradation [of the Earth], the tools for identifying it and understanding its causes, and hopefully for informing genuinely intelligent design decisions in the future” (Pitt, 2009). This last part of the quote on how STEM domains can provide inputs for decision-making resonates with the competences Swedish students on technology need to develop: “identifying problems and finding technological solutions to these problems, as well as critical analysis of modern technology usage and its everyday interaction with people and society” (Schooner et al., 2017).

In the literature about competencies for sustainability in engineering classes, the data revealed that to have a sustainable approach one needs to get specific competences on the interactions between technical systems and its context of production, use and disposal (environmental, cultural, political, normative, social context). Indeed, (Quelhas et al., 2019) defines 8 competences (systemic thinking, ability to solve problems, ability to work in interdisciplinary group, critical thinking, normative competence, self-knowledge competence, strategic competence, contextualization and future vision) and by analyzing those competences, we understand that to have a sustainability approach, an engineer has to understand more than only a technical field. An engineer has to understand how technical systems impact (in a positive and negative way) natural (the environment, earth system sciences) and human (culture, economy, norms, at individual and collective level) systems through all its life cycle stages. This requires a multidisciplinary education which offers a holistic vision of technology. The competences needed to get competencies defined by (Quelhas et al. 2019) are hard to get if disciplines are segmented (Guerra, 2017). Also, a pluri-technic approach gives students a holistic view of technical issues and the mix of different disciplines into a class provides interdisciplinary context. There is therefore a real challenge in training engineers in complex and systemic issues so that they learn how to work and take action in uncertain times, with an increasing risk of socio-ecological disasters.

The state of the art seems to be quite clear that we know what kind of competences are needed to fully integrate sustainability in engineering education. However, little implementation of these competences in training courses is done. In this paper, we express the hypothesis that the institutional frameworks in which engineering education takes place do not allow for the spontaneous implementation of these skills and learning modes.

The goal of this paper is to question the limitations of the evolution of engineering training in the face of complex environmental and social challenges. To do that, the researchers reported the results of an exploratory workshop undertaken in an attempt to formulate an engineering education framework that could better address and integrate sustainability issues. This framework is a French national framework. The goal is not to build a new educational framework on sustainable design but to point out the difficulties posed by the current institutional training frameworks to develop specific ones on sustainable transitions. One of the potential outputs is that competences might be more relevant than disciplines to design global framework for new curricula on sustainable engineering.

Research methodology

Descriptive study through a workshop

Our methodology can be positioned in the Design Research Methodology (Blessing and Chakrabarti 2009) which is represented in Figure 1. This paper can be positioned at the “Descriptive Study I” stage. Indeed, the main goal of the researchers being the integration of sustainable stakes in engineering education, the researchers collected data to “elaborate the initial description of the existing situation”. This paper describes a workshop that tests the capacity of an institutional and national training framework to integrate complex environmental and social issues; this framework being the French national accreditation process for engineering curricula. Thus, the goal of this experiment is to understand the difficulties of integration of sustainability in the evolution of current engineering programs. This experiment only allows us to formulate a hypothesis that should be implemented in a prescriptive study in future works. The positioning of our work in the Design Research Methodology helps us defining and structuring the following steps of the study (see 4.5 What is next?).

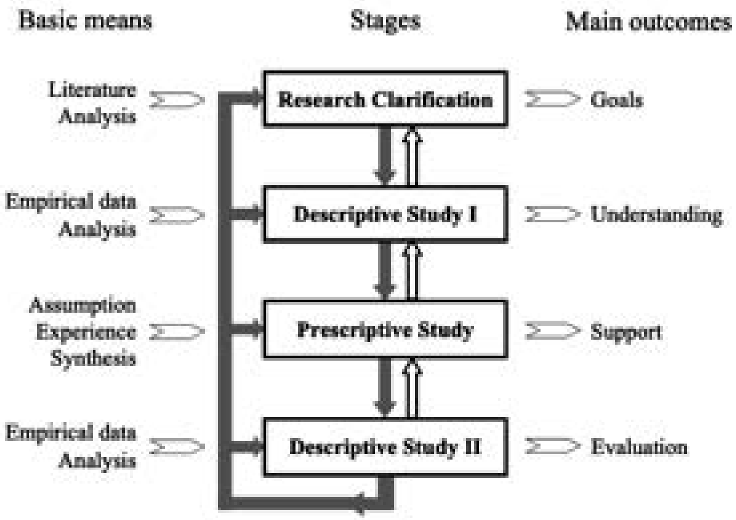

Figure 1: Design Research Methodology

The workshop has been created by the authors from scratch. The different steps are defined in the next section. The format of a workshop allows us "to iterate and thus refine and moderate our research design over time and in different context" (Ørngreen & Levinsen 2017). Even if this paper doesn't present an iteration, the workshop format offers this opportunity to continue the consolidation of this research in future works.

Details of the study

The exploration work has been conducted based on a one-day workshop at the University of Technology of Troyes on its 25th years anniversary celebration. The workshop was open to all members of the university and it was announced as a "workshop organized by students on sustainability: perma-engineering and sustainability". 7 other workshops were conducted that day, organised mainly by teachers.

Figure 2: Photo of both groups working in their sustainable wheel (step 4)

Our workshop was the most successful one, with a participation rate of 33%. 4 students from master's and engineering curricula were leading the workshop. Figure 2 shows participants working on their "sustainable wheel" (step 4 of the workshop). 15 participants joined the workshop at different times (some came just the morning or the afternoon) and were divided in 2 distinct groups of 5-6 individuals each. At least 11 people were present continuously (morning and afternoon sessions). The groups were composed of students (one of them coming from another European university), employees (administrative and teachers) and direction staff representatives, as it can be seen in Table 1.

Table 1: Details on participants

Participant N°	Age category	Nationality	Population type	Main educational background
Participant 1	<25	French	Student	Materials Engineering
Participant 2	<25	French	Student	Materials Engineering
Participant 3	<25	French	Student	Mechanical Engineering
Participant 4	>40	French	Teacher-researcher and administrative staff	Nanotechnology
Participant 5	<25	French	PhD Student	Materials Engineering
Participant 6	>40	French	Teacher-researcher	Mechanical Engineering
Participant 7	<25	Scottish	Student	Mechanical Engineering
Participant 8	<25	Swiss	Student	Ecological Management
Participant 9	<25	French	Student	Materials Engineering
Participant 10	25 – 40	French	Administrative staff	Management
Participant 11	<25	French	Student	Informational systems
Participant 12	<25	French	Student	Materials Engineering
Participant 13	<25	French	Student	Mechanical Engineering
Participant 14	>40	French	Administrative staff	Literature

Information about 1 participant is missing.

Among students, a large majority of them were also linked to the master on sustainability of the school, which is about adding 1 semester on "engineering and management of the environment and sustainable development" to the classic engineering curricula. This information is not added to Table 1 as it doesn't constitute the main educational background of the participants of the workshop.

Participants related to the master on sustainability:

- 1 student was following the master on sustainability in the same semester where the workshop took place (fall 2019)
- 2 students followed the master on sustainability after the workshop (fall 2020)
- 2 students expressed their strong interest by following the master on sustainability and have done their first internship in a research laboratory on sustainability (spring 2021)

This workshop was meant to be led into the French institutional training frameworks for engineering imposed by the Commission des Titres d'Ingénieurs (CTI, standing for Engineers Titles Commission). The CTI framework structures all the aspects of engineering curricula. To be certified by the CTI, engineering schools have to follow a specific process and provide documents justifying the relevance of their curricula (current and new ones) regarding current jobs and regarding the school's strategy. The documents are pre-defined and can be found on the website of the commission. For this workshop, we decided to focus on only one specific aspect of the framework which is the name of the provided training and the coherence between the name and the content of the training. There is a specific nomenclature for naming the specialties of engineering titles. The nomenclature is updated frequently, and the last version found is presented in annex 1. Thus, the main goal of the workshop was to create a new engineering training programme, starting from choices in the CTI nomenclature of the name of the new training and then going more deeply in the structure of the new training programme.

The workshop have been segmented into 4 parts (described in Figure 4):

1. Introduction of the challenges to meet before the end of the century and presentation of the objectives of the workshop (scientific content) – 20 minutes.
2. Choice of a domain from the CTI framework (domain of expertise) - 15 minutes.
3. Mind map of the constraints for the new curricula they want to create - 45 minutes.
4. Proposal of topics for contents and modality for new competencies on a “sustainability wheel” – 1 hour.

Figure 3: example of a diagram shown in step 1 (Doughnut economy from Kate Raworth)

For the first step of the workshop, a presentation of approximately 30 slides has been presented to explain to the participants the current environmental challenges. One of the diagrams presented is visible on Figure 3. This presentation has been created around pictures extracted from an academic literature review (diagrams from (Court & Fizaine, 2017) on EROI for global coal, oil, fossil fuels) and a synthesis of the global stakes (planetary boundaries from (Steffen et al., 2015), diagrams showing the evolution of CO2 emissions until 2100, diagrams from reports on decoupling and its impossibility).

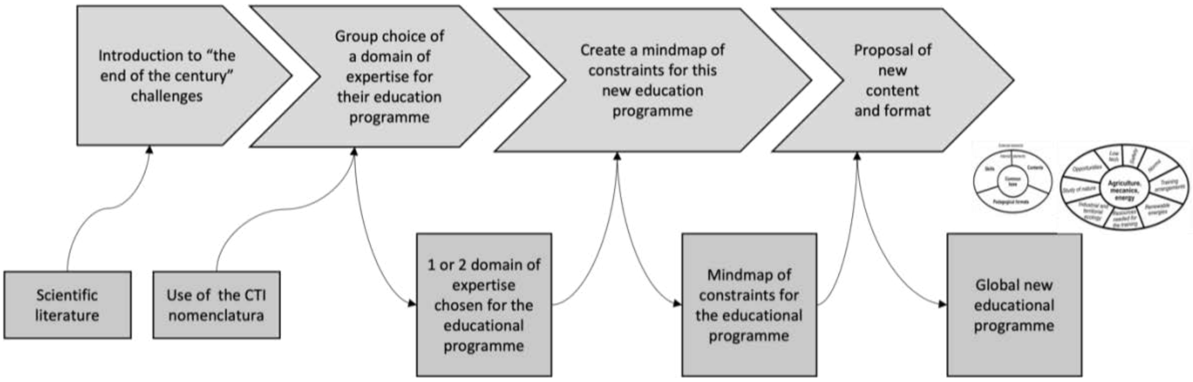

Figure 4: Workshop steps

The two groups went through the entire workshop (the four steps). People from undergraduate, research, teaching and direction staff constituted each group. The productions of the groups were kept and analysed after the workshop.

Results

Below are the results that participants received following the four steps of the workshop. We decided to present the results following the chronology of the workshop. There isn't any subsection for step 1 as no results came out of this phase.

Step 2: domain of expertise

Both groups faced difficulties to choose a domain from this framework and had the willingness to build a pedagogical curriculum out of the framework. One group did so while the second one finally decided to choose to combine three domains of the framework to address a wider scope. The first group chooses to start on a common base of skills: "common foundation of perma-engineering". They decided not to respect the CTI framework because the competences had to be transversal and not be restricted to one engineering domain. The second group chose the formation "agriculture, mechanics and energy: training the engineer in sustainable agriculture that considers today's mechanical and energy constraints".

It took 15 minutes for both groups to choose the domain of expertise. Even if a choice was made, both groups did not respect the CTI framework from the start while it was the only rule the organisers gave them.

Step 3: mind map of constraints

Each group has elaborated a mind map of the constraints. It took 45 minutes for both groups to build the mind map.

Group 1 identified thirteen constraints that we can regroup into three sections:

- Personal commitment of people: personal values, creativity, open-mindedness (addressing everyone, including those with opposing values).
- The complexity of the knowledge to be acquired on sustainability: knowledge of the issues (social, biodiversity, climate and resources), problematized knowledge (intelligibility of knowledge, reticence), global transversality and complexity of the issues.

- The institutional framework: training time (2 or 3 years), training of people, dissemination of the approach, policy, the weight of industrialists, institutional organizations, CTI.

Group 2 identified sixteen constraints that we can also regroup into three sections:

- Personal commitment of people: competence and convictions of teachers/researchers, ethics, consumption.
- Specific knowledge: design (recycling, reuse), technology, land use (deforestation, food waste), water management, biodiversity, eutrophication, resource depletion (biotic resources, abiotic/fossil resources, extraction), soil depletion.
- Structural mechanisms: financing (the current business model requiring partner companies for financing), the need for hiring, regulations, health and safety, working conditions (flexibility).

Step 4: sustainable wheel

Each group has elaborated topics on a "sustainability wheel". The two wheels obtained are very different in terms of content and structure.

The first group chose to build a common foundation for perma-engineering dividing its wheel into three categories: skills, content and training cycle. Each category was divided into two subcategories "internal" and "external" elements. The internal elements were inside the wheel while the external were outside.

The second group suggested a wheel divided into themes: industrial and territorial ecology, means necessary for training, pooling, recycling and reuse, study of climates, permaculture, stakeholders in training, study of climate and geopolitical issues, standards and regulations, health and safety, renewable energies, opportunities, training arrangements, low tech. Each theme was detailed in subpoints (between 1 and 6 subpoints).

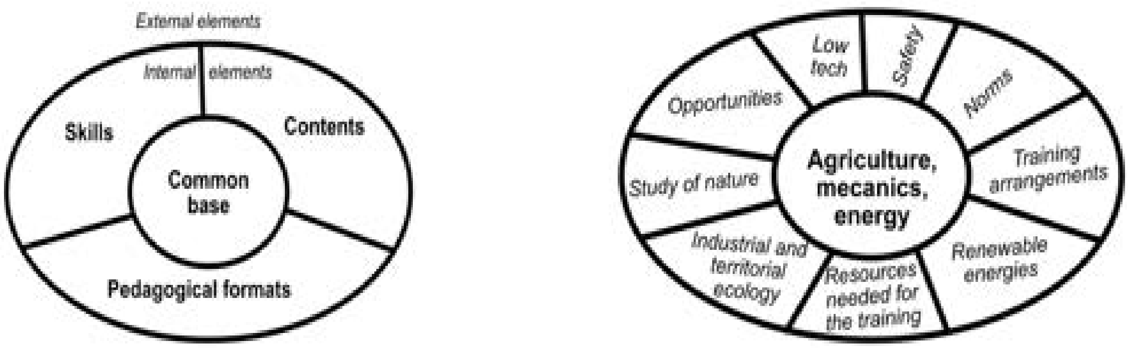

Figure 5: structure of sustainable wheel of group 1 (left) and group 2 (right)

The final "sustainable wheels" in paper format can be found in annex 2 (Figure 6 and 7). They have been represented schematically and translated in English for better understanding. All the results obtained during the workshop (materials created by the participants) as well as details of the participant's profiles have been kept and can be given upon request. The original materials are in French.

Analysis and discussion

The conclusion of the workshop was that both groups wished to leave the CTI framework because they felt "cramped" into it. This framework let at most a disciplinary combination of study fields. This section discusses the possible reasons for this feeling and tend to explain why. The first subpart discusses the results per group and a global discussion on education for sustainable development. The second subpart is focused on the limitations of the experiment which are important to have in mind to understand the outcomes and the possible next steps to follow (3rd subpart).

What are the corresponding characteristics with the literature found in the proposals?

First group analysis

The wheel of the first group seems very structured and has a very high level of abstraction, so it may seem difficult to build a training programme from the rendering. The absence of CTI constraints allowed the group to create a training by detaching itself from what already exists. Strong points emerged from their work such as:

- The need to break the understanding of the university as a « citadel » and to make it become an open place (linked to the imperative of dissemination of universities express in (Lozano et al. 2013)).
- A stronger anchoring in the territory so that the latter benefits from the knowledge produced within the university for its social development ("putting its training and professional future in context").
- A stronger link between students' associative activities and "classical" courses.
- A multidisciplinary and multi-stakeholder approach to training (also found in the literature as most of declarations, charters from higher education institutions emphasize on transdisciplinarity and the importance to involve different stakeholders see Part 3 of (Lozano et al., 2013).

The first group developed the idea of creating a common foundation, so it was much easier for its members to detach themselves from the existing situation in universities. They talked about the issues of sustainability and tried to translate them into thematic action plans. Due to a lack of time, the themes defined remain complex and a bit abstract. However, we see the emergence of atypical ideas. For instance, the fact of implementing a semester abroad sticks out in a "context where a carbon budget is to be respected". Ecological rationality will oblige students to travel to a foreign country by alternative way and therefore to manage this journey as an integral part of their whole semester experience, which can lead to a certain form of new 'way of life'. This challenge may seem easy for exchanges among European countries but will be much less so for exchanges of students with Asian or American countries. Alternative means will, therefore, have to be put in place.

Furthermore, the link between the territory where engineers are trained seemed to be important for this group. These reflexions can be linked to the work of (Zaluski et al., 2021) on territorial absorptive capacity which is "the interactions and interrelationships between them and several other institutions and public bodies". The interaction between future engineers from different fields and the territory where they study can be a way to reach the transdisciplinary competence (Tejedor et al., 2018). Indeed, engineers will have to deal with grounded problems and consider how their technology will impact individuals, communities in their territorial context. Also, the multidisciplinary approach to teach technology is seen as essential in the scientific literature but also difficult to put into practice as teachers can lack social support (Aarnio et al., 2021).

Second group analysis

The second group produced a wheel with more content but less structured, where the highly technical content is brought up to the same level as the course format. This lack of structure can be attributed to the lack of time available to both groups to build their wheels. Here are the three areas that stand out for its content:

- The need for immersion in an economic context: the student must be employable at the end of his training course.
- Learning a strong knowledge base on the theme of sustainability (can be found in all the declarations made by higher education institutions through the last 30 years (Lozano et al., 2013).
- The presence of specific experimental sites within the university.

On the contrary, the second group chose to start from the chosen field of expertise (agriculture, mechanics and energy) to go back to the issues of sustainability. The group, therefore, established itself in existing fields of activity (farms, agricultural mechanics) and started from technical needs to try to achieve the challenges of ecological transition. This approach positions itself within the existing system and makes it difficult to detach oneself from it in order to find appropriate modifications to address the issues of ecological transition. This group has therefore made proposals that can be anchored in both a strong and a weak sustainability perspective. Also, this group emphasized on the necessity to be anchored into agricultural practices (not only through projects of 1 semester but through a total immersion). This point is quite linked to the proposal of the Turin Declaration ("Develop partnerships with the private and the non-profit sectors to transfer knowledge and commercialize new technologies that advance sustainable development").

The areas exposed by group 2 on experimental sites correspond specifically to the competence "problem-solving" exposed by (Quelhas et al., 2019). Indeed, this competence is "the ability to apply engineering design while creating solutions that meet specific needs, still taking into account other dimensions such as public health, safety and well-being, as well as global, cultural, social, environmental and economic factors". Group emphasized on this need to put into practice in a real context what was learned in theory classes.

Education for sustainable development

- Education for sustainable development (ESD) is categorized into 3 types by (Vare & Scott, 2007) Type 1 approaches assume that the problems humanity faces are essentially environmental and can be understood through science and resolved by appropriate environmental and/or social actions and technologies. It is assumed that learning leads to change once facts have been established and communicated.
- Type 2 approaches assume that our fundamental problems are social and/or political, and that these problems produce environmental symptoms. Such fundamental problems can be understood by means of anything from social-scientific analysis to an appeal to indigenous knowledge.

- Type 3 approaches assume that what is (and can be) known in the present is not adequate; desired 'end-states' cannot be specified. This means that any learning must be open-ended. Type 3 approaches are essential if the uncertainties and complexities inherent in how we live now are to lead to reflective social learning about how we might live in the future"

Types 1 and 2 belongs to ESD1 and corresponds to "the promotion of informed, skilled behaviours and ways of thinking, useful in the short term where the need is clearly identified and agreed". Type 3 belongs to ESD2 which is "building capacity to think critically about what experts say and to test ideas, exploring the dilemmas and contradictions inherent in sustainable living." (Vare & Scott 2007). ESD1 and ESD2 are complementary.

The proposals provided by the 2 groups seem to correspond gather elements from type 1, 2 and 3. In group 1 proposal, most of the content in "internal elements" in "skills" and "contents" are related to ESD1 as skills are oriented towards the mastering of 1 type of discipline each time and on specific knowledge (biodiversity, resources, climate stakes). Nonetheless, the pedagogical formats are more related to ESD2 as critical thinking, operating in an unknown context and collaborating with all stakeholders outside the University. In group 2, the content of the training is also more oriented on ESD1 as it is about putting into practice technical and social tools to improve the sustainability of the agricultural sector. This group emphasized on the importance of being anchored into an economic context (trainingship in agricultural sector). It is quite hard to define if this pedagogical format corresponds to ESD1 or ESD2. Also, as this group focused on the disciplinary area chosen in the CTI nomenclature, they didn't succeed to explicitly to provide elements which could be related to ESD2. It seems that following the nomenclature was a hindrance to the implementation of ESD2 elements. Does this type of nomenclature go against the basic principles of sustainable engineering?

What are the limitations of the experiment?

Context of the experiment

Initially, the conditions under which the workshop takes place are specific. Indeed, this exploratory work was carried out in a heuristic approach. The workshop was planned in order to do some animation (in a festive framework of the 25^{th} anniversary of the University) and not specifically to write a scientific article. The information obtained proved interesting to analyze and use after the event. This results in the non-recording of exchanges and the non-preparation of an analysis grid prior to the workshop. The workshop was carried out in order to have a first intuitive version of what an engineering training on sustainability could be. The CTI framework was given as a constraint due to the French context (as participants had to create a French engineering program). It was the non-respect of the CTI framework by both groups that surprised the workshop organizers.

Participants: few and from the same context

The number of participants was low. For this reason, this study is intended to be exploratory only.

Another specificity is that the participants came from the same university (University of Technology). No one outside this context was present. There was no control over the participants profile present at the workshop, nor was there any specific request to certain parts of the population. The population of participants was therefore heterogeneous. In the end, this was positive in the sense that discussions between stakeholders in a training course could take place. This co-construction seems indispensable to us with regard to the future of sustainability. The limit is the absence of stakeholders outside the University (alumni of the University, education experts outside this context, future employers of the students, citizens) which would have brought a vision less marked by the context of a university of technology (Pritchard & Baillie, 2006).

The question of experts and non-experts

The explanations from the scientific literature (phase 2 of the workshop) seemed too complex in relation to the level of knowledge of the individuals present. Indeed, each slide presented a diagram describing an environmental dysfunction phenomenon (depletion of raw materials, disruption of the carbon cycle, and so on). Participants were unable to understand all the explanations due to their complexity. However, they asked for a re-explanation during the workshop's constraint expression phase (phase 3). The participants returned several times to the sources that had been offered in the introduction and were able to appropriate these contexts by reusing them directly in the mind map of constraints. Thus, despite a certain complexity of the explanations in the introduction, the information given was relevant to the participants' reflections and productions.

Given the participants knowledge disparities, we can question the legitimacy of the work of non-experts in sustainability to discuss the integration of ecological issues in engineering education. Based on the work of (Yesilada et al., 2009) that expertise allows greater precision and accuracy in the choices made than ignorance on a subject. Expertise also increases the robustness of the results. This is of course valid for a large number of disciplines. However, is it valid for the field of sustainability? Would the integration of non-experts be relevant in the end? Some works in the field of environmental planning show that the integration of non-experts allows co-creation and a better matching of results to the expectations of the different stakeholders (Cook, 2011). Can the construction of an engineering education for environmental transition only be done with researchers specializing in the field?

What is next?

An upstream assessment of each participant's level of knowledge on sustainability would be relevant to ensure the relevance of the participants' proposals. Also, a repetition of the workshop in many contexts would make the hypothesis formulated more robust. Additionally, a recording of the interactions between each group would make it possible to understand the pathways and blockages that lead some groups to bypass or dispense with institutional frameworks.

This approach was based solely on the name of the potential training imagined by the participants. In this paper, we chose only 1 aspect of the accreditation process which was the process to define the name of the new curricula. Other elements more complete and complexe are part of the accreditation process, the writing of a synthetic document on the school, a general note of strategic orientation of the school, constitution of a note for the Consultation of the National Directory of Professional Certifications. Other workshops dealing with the other aspects of the certification process could also be analysed to see whether other institutional elements could be used as blockages to the development of engineering education around sustainable transitions.

Conclusion

The workshop detailed in this paper was an exploratory experiment, involving a restricted number of participants. It was divided into 4 parts: an introduction of the challenges from a scientific point of view, the choice of a domain of expertise within the CTI framework, the elaboration of a mind map of constraints for the new curricula each group of participants wanted to create and a final proposal of contents and modality for this new curriculum. Both groups succeeded to path through the 4 steps of the workshop and produced a graphical representation of their proposal.

It can be concluded that participants faced difficulties positioning themselves within the imposed CTI framework because they had the feeling that this framework couldn't let them reach the issues of strong sustainability. The disciplinary approach utilised within this workshop was determined to restrict the evolution of engineering education. This disciplinary approach has been chosen by institutional frameworks. These frameworks can, therefore, constrain thinking for strong evolutions of training. Ecology being a holistic approach involving disciplines other than those offered by the French institutional framework CTI and future work could be conducted to evaluate the relevance of this framework for designing training courses addressing complex environmental and social issues. This heuristic experiment, therefore, opens up new research perspectives in the field of the evolution of engineering education and institutional frameworks accompanying higher education institutions.

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links/5fff872545851553a0417d10/Framework-Conceitual-da-Capacidade-Absortiva-Territorial-e-Desenvolvimento-Sustentavel.pdf).

Appendix 1

Table 2: List of wordings that can be used in the constitution of a speciality title taken from (Commission des titres d'ingénieurs 2018)

1	Aéronautique et espace (ou aérospatiale)	Aerospace engineering
2	Agroalimentaire	Food engineering
3	Agro-industries	Agro-industry
4	Agronomie	Agricultural engineering
5	Automatique	Control engineering
6	Bâtiment	Construction engineering or Building engineering or Civil engineering
7	Bioinformatique	Bioinformatics
8	Biotechnologie	Biotechnology
9	Bois	Wood technology
10	Chimie	Chemistry
11	Électronique	Electronics
12	Emballage et conditionnement	Packaging
13	Environnement (pas seul)	Environment (and…)
14	Ergonomie (pas seul)	Ergonomics
15	Génie biologique	Bioengineering
16	Génie biomédical	Biomedical engineering
17	Génie chimique	Chemical engineering
18	Génie civil	Civil engineering
19	Génie de l'aménagement	Urban planning engineering or Urbanism and spatial planning
20	Génie de l'eau	Water (resources) engineering
21	Génie des procédés	Process engineering
22	Génie électrique	Electrical engineering

23	(Génie) énergétique	Energetics (engineering)
24	Génie hydraulique	Hydraulic engineering
25	Génie industriel	Industrial engineering
26	Génie maritime	Marine engineering
27	Génie mécanique	Mechanical engineering
28	Génie nucléaire	Nuclear engineering
29	Génie physique	Physical engineering
30	Génie urban	Urban planning engineering
31	Géomatique	Geomatics
32	Géosciences	Geosciences
33	Gestion des risques	Risk management
34	Horticulture	Horticulture
35	Informatique	Computer science
36	Informatique industrielle	Computer engineering
37	Logistique	Logistics
38	Matériaux (precision possible du tyme de matériaux : polymères, céramiques, composites, métalliques…)	Materials science or… materials
39	Mathématiques appliquées	Applied mathematics
40	Mécanique	Mechnaical engineering
41	Mécatronique	Mechatronics
42	Microbiologie	Microbiology
43	Microélectronique	Microelectronics
44	Microtechniques	Microtechnology
45	Multimédia	Multimedia engineering
46	Paysage	Landscape engineering
47	Photonique	Photonics
48	Plasturgie	Plastics engineering
49	Production (pas seul)	Production (and… of)
50	Réseaux	IT networks engineering
51	Robotique	Robotics
52	Santé (pas seul)	Health (and…) or… for health
53	Sciences de la Terre	Earth sciences
53	Sécurité (pas seul)	Security (of…)
54	Systèmes () embarqués	Embedded () systems
55	Systèmes d'information	Information systems
56	Systèmes ferroviaires	Railway systems
57	Systèmes numériques	Digital systems
58	Technologies de l'information	Information technology
59	Télécommunications	Telecommunications
60	Textiles (et fibres)	Textiles (and fibres)
61	Topographie	Topography(-surveying)
62	Travaux publics	Public works or Civil engineering

The CTI framework is composed of the dimensions present in the Table 2. « The specialty title of an engineering program must consist of no more than two wordings taken from the list below. In the case of two headings, they may be linked either by a conjunction ("and") or by a preposition ("of", "for", etc.). » (Commission des titres d'ingénieurs 2018)

Appendix 2

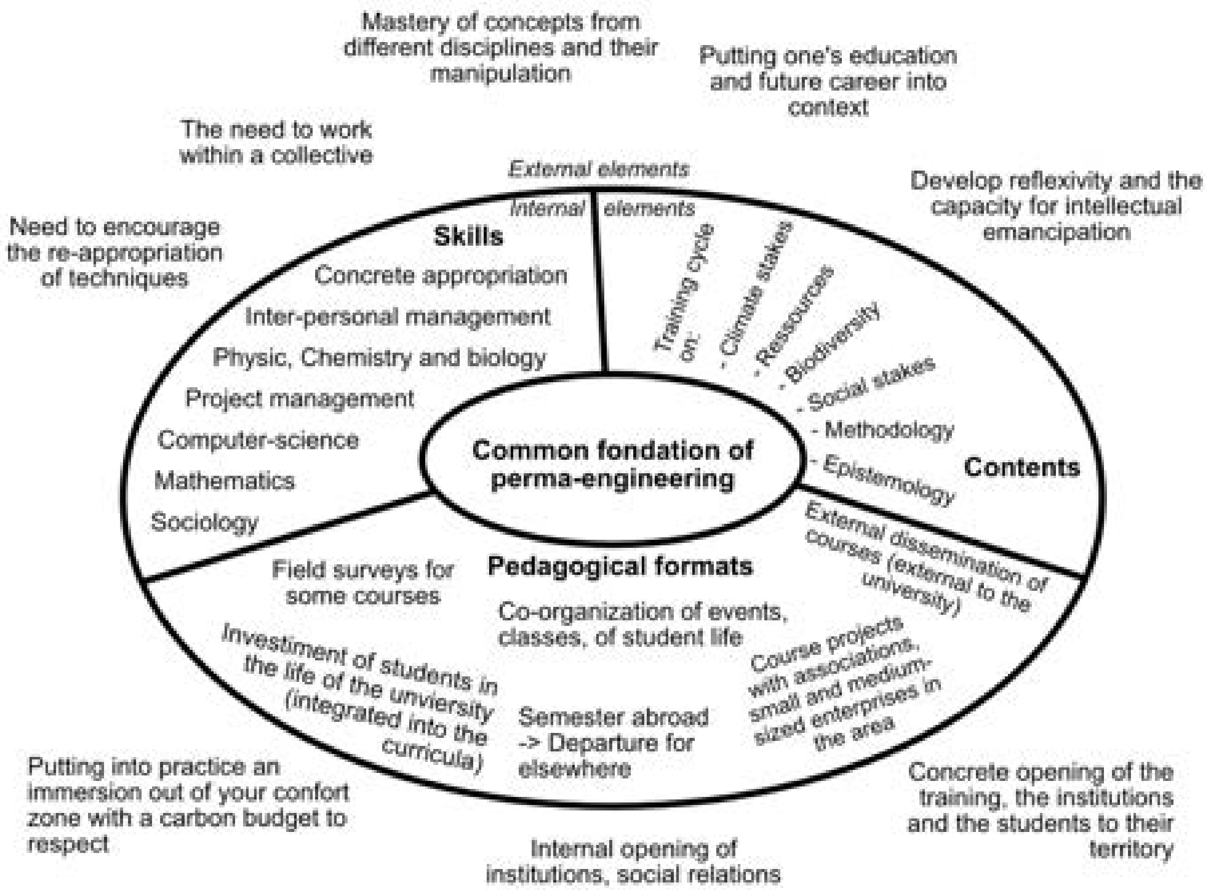

Figure 6: Final production of group 1

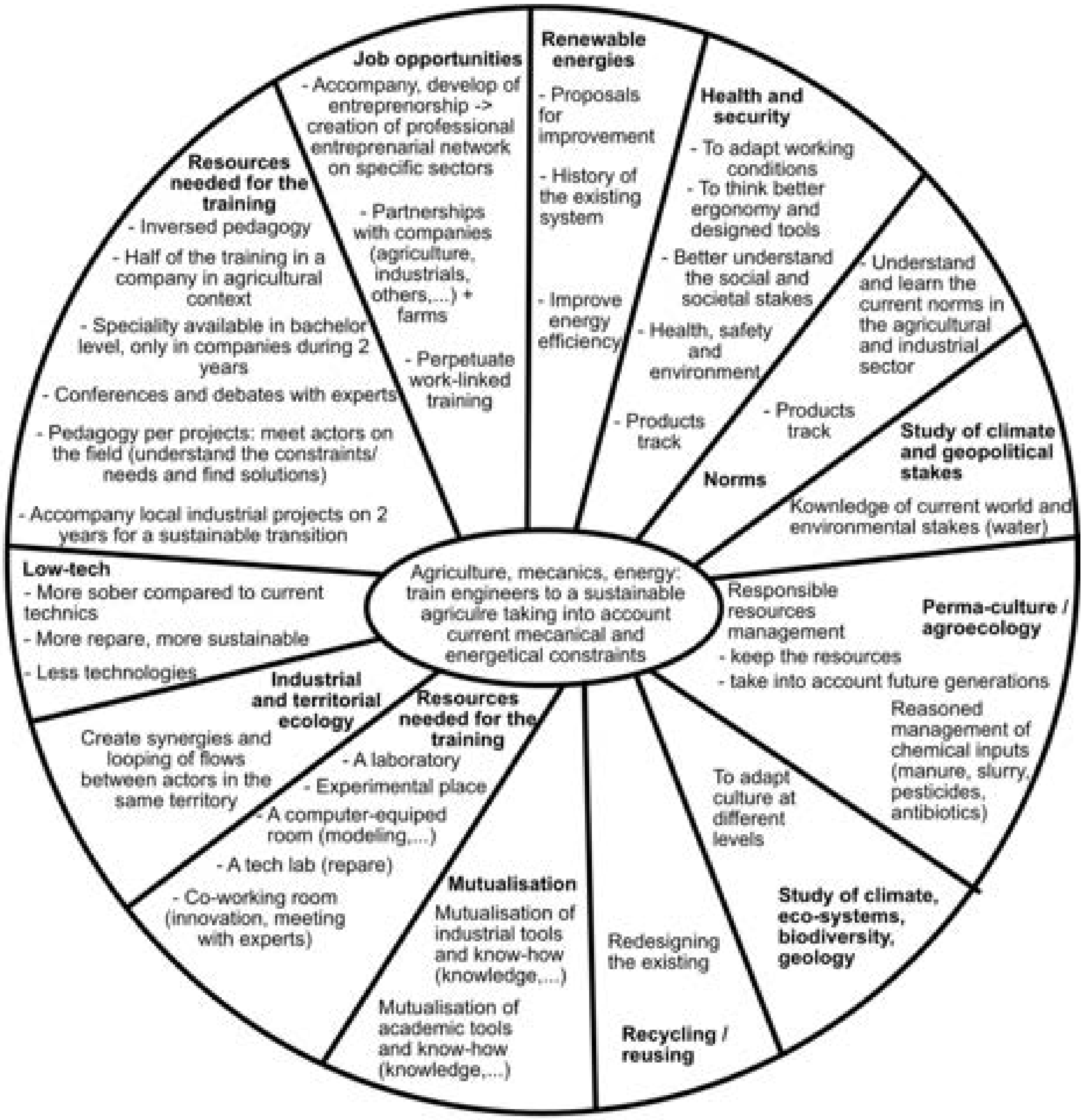

Figure 7: final production of group 2

Book Review

Enkindling "gestaltic" stimulation of knowledge encounters through perspectives in practice: Affordances of design-based concept learning

A review of Ineke Henze & Marc J de Vries (Eds.) (2021) *Design-Based Concept Learning in Science and Technology Education*, Brill/Sense Publishers, The Netherlands

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Aim, purpose and organisational framework

The book is a part of the series of publications on International Technology Education Studies. It addresses an emerging niche area in learning, situated at the convergent interface of design and learning of concepts in science and technology. Emerging from any cross-disciplinary overlap or convergence is the challenge of identity, which pertains to examining the kind, purpose and outcome of overlap in domains. This includes examining the nature and extent of overlap, the conditions and considerations, and the productive emergence achieved in the process. In the same breath, this book captures experiences, insights and reflections of practitioners engaged with design-based learning concept learning (DBCL) from diverse domains of practice. Structurally, the book is organised into five parts. A total of 16 chapters unfolds in: Part 1 (2 chapters) as an introduction which foregrounds the theoretical positioning; Parts 2 (5 chapters) & 3 (5 chapters) dedicated to concepts in domains of Science and Engineering/Technology, respectively; Part 3 (3 chapters) is about methods and approaches, and Part 4 on the conclusion (1 chapter) consists of a reflective piece and possibilities ahead.

The succinct preface by editors acknowledges the efforts towards convergence or a meeting of three rivulets salient to learning: concepts, design-based processes, and multi-disciplinarity in education. Incidentally, these rivulets respectively symbolise and represent the content, process and (systems) approach features that shape learning. Much of the contributions are from the researchers in Delft University suggesting an effort towards synthesis with DBCL as a larger framework for paradigmatic reconciliation of practices from the various learning domains. There are a few contributions from Israel, Sweden and the USA, which offer perspectives from different contexts. While the contributions serve to instantiate DBCL experiences, they also bring flavours of interpretations and diverse forms of accommodating design in practice.

Conceptual head-start

A reader provoked by the book title would be keen on understanding what DBCL implies, how it is characterised, and learn what unique facets of learning may come to the fore following such an approach. Counter to this intuitive flow is the first part on Introduction, which consists of two chapters, one on the formulation of DBCL and the other engaging with the notion of integrated Science, Technology, Engineering and Mathematics (iSTEM) Education. At the onset, the first chapter by the editors, Henze and de Vries, posits that design-based learning belongs to the 'family' of social constructivist approaches to learning. While a familial association with inquiry-based, project-based, problem-based and design-based learning is made, there is a need to strengthen the identity or distinctiveness of DBCL as an approach. The chapter briefly navigates through the notion of concepts as being abstract in nature and the learning of concepts as cognitive re-conceptualisation. The discussion follows on with a thread on concept learning through design which foregrounds the valued contribution of design experience in making abstract concepts more tangible or operable and the use of design iterations for systematically enhancing knowledge. The next thread in this chapter focuses on agentic role of teacher in design-based learning. The chapter culminates by giving an overview of the organisation of parts and a brief on the upcoming chapters (Chapters 2 to 15).

The second chapter by de Vries affirms the role of design activities for integrating elements from S, T, E, M disciplines. DBCL is a case exemplification of iSTEM. The chapter draws parallels between the nature of science and nature of design, making a case for design enabled integration of STEM domains. The possibilities include meaningful engagement with otherwise abstracted concepts; enrichment of knowledge elements across domains; scope for addressing pre-formed, intuitive, alternate and (mis)conceptions; and developing insights into design process. One of the critical arguments developed is that dealing with an increasing number of abstract concepts coincides with a progressive employment of "epistemic" filters as learners advance in concept levels and across learning grades within a knowledge domain. This explains the gap between the reality and abstracted knowledge that a learner faces during learning, leading to a "cognitive conflict". It is argued that the DBCL experiences can form the motivational entries for enriching formal, domain concepts.

A quick reflection at this juncture elicits some thoughts. Literature in design (Cross 2006) acknowledges that design is a discipline, which is characterised by unique principles and forms of knowledge, designerly process of engagement and specific outcomes. Thus, mediations involving design proffer potentials for gaining insights about social realities and experiences, learn and know more about designing itself as well as meet an instrumental role, which involves pressing into service, the notion of design or designerly processes towards envisioning solution for an ill-structured problem. The collection of articles seems to subscribe to the latter, whereby the intent is to harness design thinking for the instrumental goal of domain-specific, conceptual learning. An interchangeable use of design-based learning (DBL) and DBCL in the book leaves a subtle, lingering dilemma about the salience of a distinctive characterisation. It is surprising that although the discussion initiated with social constructivism in the first chapter, the thread of ideas and closing emphasis in the second chapter on integrative learning has been on cognitive conflict (dissonance), which hinges upon personal constructivism. The dynamics of conflicts arising and being handled in social scenarios embedded within political and cultural landscapes of learning, need attention. Let's now turn to the next two parts of the book.

Domains, Concepts and Designerly perspectives

Teaching learning is a planned, intentional and dynamic activity. While instruction and pedagogies can be systematically developed and translated into practice, the processes of orchestrating teaching learning through 'designerly ways' (Cross, 2006) with attention to the conceptual content along with socio-cognitive, emotive and reflective discourses is critical for making learning contextually authentic and meaningful. Efforts to consciously re-align content can contextualise learning, build iterative reflection, render possibilities for meaningful application and facilitate transfer of knowledge and skills. The parts two and three of the book engage with experiences of orchestrating the conceptual content in STEM domains. The chapters three to twelve represent a diverse set of domain-specific experiences, guided by an effort to integrate design-based aspects for enriching process as well as outcomes of learning. Evidently, a differential absorption of the notion of design manifests in the varied focus and emphasis in the experiences reported.

Chapter three by Bulte, Meijer and Pilot claims for a conceptually enriching prospect in a different representation of chemistry content contoured on design-based student tasks as opposed to the hierarchised contingency of conceptual ideas in conventional curricula. The DBCL perspective in chemistry foregrounds contextualising content in a manner that draws attention of learners to inquiring meso-structures thereby bringing into focus the conceptual relationship between macro and micro-thinking. The authors locate the DBCL effort in the theoretical framework on activity theory and exemplify an emergent instructional design for acquiring the concept of nature of matter at the secondary school level through an engagement with design-based task.

The fourth chapter by Apedoe, Ellefson, and Schunn argues for the need to support concept acquisition and change through a systematic process of learning cycle that interlaces dialogue between elements of design and science. The authors emphasise the pedagogic value of projects in encouraging design thinking that affords use of knowledge of materials and focal concepts in secondary school chemistry to develop a sense of big-ideas in connected subsystems of a larger functional system such as the heating/cooling system. A case is made for how a DBCL project allows scope for addressing alternative, pre- or misconceptions held by students as well steers their understanding towards designing a realisable prototype.

Chapter five by Breukelen details the task processes and scaffolding strategies that contributed to an enhanced students' performance and conceptual grasp of ideas on circuits and electricity. The author chooses to position the study at the interface of cognitive frameworks of content acquisition involving knowing and application, processes supporting conceptual change and problem-based scenarios in learning. The DBCL experience illustrates the use of FITS (focus on challenge, investigate scientifically, technological design knowledge application and synergy of science and technology) as a pedagogic model for realising a "design-based science interference". The learning task encouraging the designing of a circuit affords an extension of ideas in electricity and facilitated meaningful discussion on conceptual nuances among the students and the teacher.

The next chapter by Dopplet and Barak reports a DBCL experience concerning electronics and mechatronics at the middle and high school levels in two cultural settings of practice, Israel and the USA. The authors emphasise the value of design processes in engagement with projects and position the DBCL experience within the pedagogical orientations of problem-, project-based and systems thinking. While design projects can support learning of concepts in physics and engineering, the authors simultaneously underscore the need for a critical interweaving of professional development and formative assessment practices along with the DBCL practice.

Chapter seven by Spandow foregrounds the salience of designerly language of modelling. The author signifies attention to historic developments in the field, using models for contextualising integrals and differentials, and demonstrates how working with models can mediate developing mathematical understanding. The author claims that modelling can enable application of mathematical ideas for seeking societal welfare. The DBCL experience positioned with the model-based learning framework emphasises the role of modelling, history-informed teaching and use of stock-and-flow software for grounding concepts in calculus at high school level.

Gómez Puente in chapter eight elaborates on a DBCL experience involving students and teachers from the Bachelor in Engineering programme. The work positioned in project-based learning framework discusses the valued impact of design process approach in meaningfully supporting students and teachers to accomplish engineering projects. Using project case examples, the author asserts the salience of DBCL as an operative framework of instruction. The chapter demonstrates how performance of students increased significantly for the teams working through a DBCL approach of project engagement.

Chapter nine by Svensson discusses the engagement involving students and their teachers in Swedish secondary schools. Using inquiry and modelling as principles of DBCL, the author makes a case for directing learners' attention to thinking about systems in everyday lives, and recognise the interplay of the critical pillars of technology, namely; information, matter and energy in appreciating the components, connectedness and flow in everyday functional systems such as the transport system. Locating the DBCL experience within a project-based learning paradigm, the author argues for a conceptual and instructional framework to enhance learning.

The tenth chapter by de Haan-Topolscak and Smits represents an investigation into the process designing itself. The authors report a study undertaken with secondary school students opting Technasium. The study explored how students engaged with the idea of requirements in design briefs. While design briefs ought to realistically reveal about the structure and functional aspects of designed artefact, the students seemed to focus on what they would desire to see (an ambitious envisaging) of the artefact. They also did not exhibit pre-knowledge about the significance and purported function of design briefs. The authors suggest a need for foregrounding and discussing this knowledge in DBCL learning engagements.

Chapter eleven by Wells relates to DBCL experience with engineering students, pursuing a course in biotechnology in the USA. The author develops a case for how a 'design-based biotechnical learning framework' can engage learners in carefully sequenced problem scenarios which contribute to promoting the STEM conceptual understanding. The author demonstrates how a designed learning engagement with convergent and divergent questioning which are at the core of PIRPOSAL (problem identification, ideation, research, potential solutions, optimization, solution evaluation, alterations, and learned outcomes) process, can be an effective pedagogical model for fostering learning and helps address larger technological concerns, such as the use of renewal energy for supporting sustainable living.

The study reported by Stevens, Kopnina, Mulder and de Vries in Chapter twelve involved industrial design engineering students in the Netherlands to integrate from an exposure to biomimicry thinking, the analogical relationship between features of structure-function salience in biological world onto artifactual design. The pedagogical model of 'design lens to biology' allowed for combining elements of project-based learning, analogical reasoning, attending to life principles and employing biomimicry thinking. The authors demonstrate that the DBCL experience encouraged students to strive for an explicit transfer of form, process or systems idea to conceptualise and design engineer an artifactual outcome.

Common to chapters three to twelve is a conscious effort to contour and enrich conceptual learning through designerly thinking. Of the ten chapters, spread over two parts, seven reported experiences engaging students from secondary or high school levels. Three contributions (by Breukelen, Gómez Puente and Svensson) explicitly attended to teachers as participants in their respective studies. Interestingly, all the experiences seemed to be guided by an effort to gain insights into either developing an *instructional framework* or *pedagogical model*, so as to nurture attention to conceptual content. The contributors seemed to accommodate design as enriching the quality of learning variously, either by choosing to *focus on design elements* (for example, attention to meso-structures for mediating relationship between macro- and micro-thinking by Breukelen; modelling and history-informed teaching by Spandow; or a focus on information, matter and energy in enabling systems thinking by Svensson) or by demonstrating an *adaptive emphasis on design process* (for example, 7-step learning cycle by Apedoe et al., design process by Dopplet & Barak; or PIRPOSAL by Wells).

The bipartite presentation of chapters as Science and Technology/Engineering concepts may raise several questions for stretching our minds: (i) How does the organisation of part two build on part one of the book, isn't the organisation antithetical to multidisciplinary foregrounding in the first part? (ii) Are the concepts covered through the domain constituency unique or distinctive (in their historic evolution, nature or affordances) and therefore call for a separation? (iii) How is the engagement with domain concepts and its treatment contoured by differential absorption of design-based learning orientations in domains of practice? (iv) Does the selection of experiences support an argument of design-based engagements having an unequivocal impact on concept learning, irrespective of the differences in perceptual (historic, social or disciplinary) proclivities toward imbibing the principles and attributes of designerly engagement? (v) Is the demarcation a means to showcase the distinct disciplinary sources of efforts towards absorbing a DBL practice? Such a flurry of questions arising from a glance at the organisational structure may be parked for some time in order to immerse with the unfolding ideas as they come along. Overall, they capture an "epistemic ferment" driven by efforts to make teaching learning effective and meaningful on one hand, and align the learning processes with designerly ways on the other hand.

Building further from the "epistemic ferment"

One of the larger questions that may come to the reader is about the substantive generalisation that can be drawn from the experiential musings of what gets qualified as DBCL. The fourth part of the book on Methods and Approaches seems to be addressing this concern.

Chapter thirteen by van der Sanden and Wehrmann argues for an epistemic positioning of design thinking as a 'mind-set' or mental model of the designer, that needs to be systematically implanted, developed and nurtured through an engagement with a community of practice. The arguments draw upon insights from Communication Design for Innovation (CDI) program at Delft University. The authors demonstrate learning in loop through a discussion of some works of students engaged in designing. While design-based learning has been argued as fostering collaborative innovation through the triple-loop model of learning, design thinking is also acknowledged for being vulnerable as it involves coping with uncertainties, awareness of one's own biases and yet keeping the mind open to ideas.

Another interesting strand drawn from experiences relates to the role of teacher in noticing and supporting the work of learners. Chapter fourteen by Stammes, Henze, Barendsen and de Vries employed the dynamic construct of teacher noticing, accessed through plans and drawings. The study not just vouches for rigorous conceptual gains in chemical thinking through an attention to nuances of student-teacher interactions but also makes an empirically-guided, evidentially-informed case for using noticing as a means to probing thinking and enhancing teachers' calibrated role in supporting designerly thinking.

Chapter fifteen by Sheoratan, Henze, Barendsen and de Vries is a continuation of the thread on teachers' role, where the verbal scaffolding offered by in-service teachers in guiding design assignments of learners has been studied. The analysis brought to the surface the different types of questions and feedback strategies used by teachers to exercise different degrees of control and help scaffold students' work. Interestingly, the directed scaffolding in terms of concept learning was found to much lesser as compared to engagement with learning processes, suggesting the critical role of teacher in calibrated leveraging of students' agency. On reflection, one realises that the book began and ended by drawing upon experiences from integrating design in teaching learning of chemistry.

Consolidation and intended takeaways

Chapter sixteen by the editors is the concluding chapter and also the last part of book. It offers a helpful analytical consolidation and invokes some critical leads for thinking. Three themes emanating from the collective DBCL experiences are discussed: variety in DBCL practice, attending to diverse roles by teacher, and nature of learning supported through DBCL. A fascinating attribute of this chapter is a combination of generalisation and inferential abstractions. For instance, the editors surmise on the flexible nature of DBCL in adapting to levels of conceptual complexities, topics and epistemological and pedagogical approaches. At the same time, several inferential claims are drawn from the thematic discussions. This includes, the correlation of abstract concepts and the plausibility of DBCL as relatively more amenable for the higher educational levels, direct instruction as a pre-requisite to inquiry and design for necessitating concept learning, the need for teachers having pedagogical content knowledge along with willingness to experiment and reflect, and functional invariance of design-based activities in meeting the three dimensions of science learning, mentioned in NGSS

(2013), namely; disciplinary core ideas, cross-cutting concepts, and addressing science and engineering practices. The chapter culminates with a call to researchers and innovators to identify, engage and address challenges in realising design as a context for conceptual learning.

Critical gatherings and closing thoughts

The book title embraces design and concept learning in the same breadth. The reader is enticed into expecting an interweaving that may offer a refreshingly different perspective, other than the one offered either uniquely through a concept-oriented or a design-oriented imagination. The attempt to rationalise and ground the idea of DBCL from pedagogical and epistemological standpoints in first two chapters does not catch momentum. The contributions from disciplinary domains seem to reflect a struggle of scheme alignment. While the chapters unfold some remarkable works in their own right, the effort to operationalise deep-seated connections with the idea and process of design needs further development. The conscious effort to reclaim identity of design paradigm in many cases comes from a compromise. The compromise is achieved, either by attending to a design characteristic (for example, addressing ill-structured problems, investigative problem scoping, iterative process, use of designerly language consisting of non-verbal codes, drawings, cognitive modelling, etc.) or relating to designerly process (for example, conjecturing, collaborative negotiations, redesigning, appropriating, etc.). While design seems to offer a paradigmatic scheme, the reader jostles through diverse pedagogical frameworks which include, project-, problem-, design-based science, learning by design, and some other models discussed in various contributions. One wonders if a clash of the two cultures of sciences and design, articulated by Cross (2006), be a reason for the felt conceptual effervescence? Positioning DBCL as a mere variant in the family constellation of allied pedagogies affirms to a conformational reconciliation with elements of design paradigm rather than carving a distinctive epistemological and conceptual niche.

The strength of this book lies in being accommodative of the multiple ways in which the elements of design thinking have been internalised in domains of practice. Identifying with DBCL as means to realising internationalities through meaningful, educative experiences is a powerful and pragmatic road ahead. The collection of articles seemed to stimulate the need for relational examining of knowledge and practice, in a "gestaltic" vein. Hergenhahn and Olson (2001) elaborate that *gestalten* (plural of *gestalt*) represents meaningful configurations or patterns that ought to be examined at a molar (rather than molecular) level or as a phenomenon in its entirety. The several contributions may serve as exemplars for not just schematising the confluence of design and discipline-oriented concepts, but also to encourage initiatives that pursue the use of designerly thinking for epistemologically and conceptually shaping the terrain of educational practice in intellectually stimulating ways. The book would be useful for any reader seeking a reinvigoration in thinking and experimenting with curricular and pedagogic practice. The book will appeal to curricular practitioners and researchers in STEM education as well as in disciplinary domains, educationists, teacher educators and teachers at different levels of educational practice.

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