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Design and Technology Education: An International Journal

Design and Technology: An International Journal

Volume 26
Number 1
ISSN 2040-8633 (online)
February 2021

Design and Technology Education: An International Journal
(formerly The Journal of Design and Technology Education) is published three times a year

Contributions
All contributions and materials for review should be made through the Journal website at:
https://ojs.lboro.ac.uk/DATE/index

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Editorial 26.1

Thinking design? Design Thinking?

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

Welcome to the first issue of the journal for 2021. As we enter what will hopefully be the final chapter of the current pandemic, this issue provides opportunities for sharing recent research alongside some speculation about how things might change and what future research may focus on. The issue includes six research articles, a reflection piece and two book reviews. The research articles fall into two categories and the first three report directly on research in design and technology activities in mainstream schooling.

However, the further three represent a slight shift away from articles normally published in the journal as each looks within and beyond design and technology education, exploring broader links with design thinking and design pedagogy. Having articles focusing on Design Thinking submitted to the journal is something new and has given us editors, not to mention a small number of our reviewers, a certain amount of soul searching. Do such articles fall within the scope of the journal? Is it beneficial to authors and readers to have them included? And ultimately, where does the journal sit in terms of the broader adoption of Design Thinking beyond what we might see as the family of design and design & technology education? Do we want to protect our territory or be open and inclusive? This is a tricky issue. A dimension that many of us take pride in is the interdisciplinary nature of design. Any knowledge is design knowledge if you need to know and understand it to make progress on a 'wicked' task. Processes of design, the wicked nature of design knowledge and design problems make the 'discipline' special whilst also providing a centre of gravity for working within and across disciplines. For some, design is even seen as post disciplinary.

So, where does the journal sit in relation to research that centres on Design Thinking, rather than exclusively on design and technology education?

As editors, we made a choice to accept articles for this issue that might appear to be coming in from left field, and we hope that readers find them as valuable, interesting and stimulating as we do. But, as always, we welcome comments and views, including on future directions.

But now to the contents of this current issue.

The first research article focuses on the use of ePortfolios. In *Long-Term Use of ePortfolios in Craft Education among Elementary School Students: Reflecting the Level and Type of Craft Learning Activities*, Auli Saarinen, Pirita Seitamaa-Hakkarainen and Kai Hakkarainen from the University of Helsinki, Finland present research from a longitudinal study on use of ePortfolios from 3rd – 9th grade in the context of Finnish National Curriculum Craft education. The authors describe the affordances of this type of portfolio as a method of documentation, including the development of digital competences. What is reported in this article builds on two previous reports, one focusing on user experience of ePortfolios over three years and a second analysing

textual and visual contents of ePortfolios across four years. This current article sheds light on the types of learning activity and cognitive processes that are made visible through the portfolios. A background to developments and types of ePortfolios is presented in advance of focusing on the reported study in which pupils worked in groups, collecting images and descriptions of pivotal events in their working and learning. Data was gathered from 2013-2018 and a detailed analysis was undertaken including interviews with eight students each with six years experience of using ePortfolios. The study revealed a shift from concrete to abstract cognitive processes, an increasing focus on procedural knowledge over technical matters and student-led over teacher-led activities. At interview students showed a critical attitude, focusing on aspects such as reflection and communication. The authors suggest more research is needed, but present a detailed and fascinating account of the impact of longitudinal use.

A second longitudinal study from Finland is presented by Marja-Leena Rönkkö and Virpi Yliverronen (University of Turku) and Kaiju Kangas (University of Helsinki). In *Investigative activity in pre-primary technology education—The Power Creatures project* they present research with pre-primary children (5-6 years old) exploring a playful investigative approach as children designed and made 'power creatures' – felted creatures containing soft circuits. The project was set within an integrative STEAM approach that was inquiry based, multidisciplinary, involved creative problem solving and hands-on activity. The aim of the study was to understand the nature of the children's activity focusing on everyday technologies and to identify pedagogical practices that support such investigative activities. Data was collected through video recording the activities of 19 young children and then analysing these using a deductive content analysis method. The article reports on the phases of the activities over a four month period highlighting teacher scaffolding and involvement alongside the children's investigative activities. Children's motivation, confidence and empathy were supported through stories, play and exploration and included constructing a circuit with alligator clips, battery, battery holder and buzzer both through 'circuit play' (in which the children were the components) and also with real components. They also engaged in hands-on craft activities, learning how to felt wool and use this to make their creatures. The article highlights the educational focusing taking place, such as dialogue and collaboration, reflection and reasoning. This joyful article provides illustrated insight into both young children's learning and the pedagogic practices that supported this.

A further article focusing on pedagogical tools in a project involving circuitry comes from Sarah Pule and Jean-Paul Attard from the University of Malta. In *Spatial cognitive processes involved in electronic circuit interpretation and translation: their use as powerful pedagogical tools within an education scenario*, they present research on spatial cognitive processes with older learners – 15 and 16 year olds studying vocational engineering technology in a Maltese secondary school. Some background and history on iconic and schematic circuit diagrams is provided along with factors that impact on our understandings of different ways of representing items and to the learning involved. Data was collected from research with a mixed gender and ethnicity class of 18 students at a point in their course where the focus was on electronic circuit assembly. The students' task was to translate a schematic circuit diagram into a stripboard layout using computer software to create an iconic circuit representation. Grounded theory was used to derive data from mainly qualitative analysis. An aspect was identifying sub sections of units that link to a particular function – what are referred to as 'chunks'. Analysis focused on the shift from symbolic to iconic representation and to two key

'chunks' of the system and indicated that while the shift from symbolic to iconic components was managed well by the novices, with more cognitively taxing aspects such as flow within 'chunked' functions, they were less successful. The authors suggest the normative practice in electronic education of starting with symbolic and moving to iconic could be unhelpful, referencing Bruner's theory that intellectual development moves from enactive to iconic to symbolic representation. They suggest that this could influence pedagogic approaches.

The research with 5 and 6 year olds presented by Rönkkö, Yliverronen and Kangas and that of Pule and Attard is quite different in many ways. But a fascinating connection is apparent when considering the enactive pedagogic approach taken with the young children and the findings with the older children. Despite age and education phase differences, there are important insights here for design and technology educators at all levels of education.

The fourth research article is the first of our articles on Design Thinking. In *Meeting the Challenges of STEM education in K-12 Education through Design Thinking* Ahsen Öztürk from Ondokuz Mayıs University, Turkey draws on international and Turkish perspectives to consider ways in which STEM education is interpreted and incorporated into curricula. The position in Turkey is interesting, wherein the technology and design and science curricula in primary and secondary schools have a focus on STEM, with technology and design emphasising creativity, innovation and user-centred design. It is also proposed that its teachers becoming mentors for other subjects. Insight into a Design Thinking approach is drawn from literature, along with its increasing application in mainstream schooling, including in curriculum and instructional design – an issue also highlighted in the final research article in this issue by Mehmet Ersoy. Multiple approaches of Design Thinking are compared. This analysis of STEM and Design Thinking then become the backcloth for exploratory research into the challenges of STEM education in Turkey, initially through semi-structured interviews with teachers and school principles and then through participating in a STEM workshop as participant-observer. The interviews revealed challenges with integrating STEM, partly because of the diversity of subjects and partly because an engineering design process and results oriented mindset was being promoted and partly because of scheduling difficulties. The STEM workshop highlighted the importance of collaborative approaches and a value of engineering in STEM including inquiry-based problem solving and engineering design process. Once again teachers highlighted challenges such as a results-oriented mindset linked to a national education focus on exams over creativity. Set against the literature review of Design Thinking, the similarities and differences in approach between mindsets of engineering and mindsets of Design thinking were compared, the latter seen as providing potential solutions to challenges identified in the exploratory research.

A second article on the affordances of Design Thinking is contributed by Ivano Bongiovanni of the University of Queensland, Australia and Dayana Balgabekova of the University of Glasgow, UK. In *Ask me if I am Engaged: A Design-led Approach to Collect Student Feedback on their University Experience* they present an innovative approach to using Design Thinking to gather feedback from Masters-level students in a Business school through a design led workshop. The workshop was held across two days and centred on students co-designing the 'University of the future.' This novel approach was explored as an alternative to the normative satisfaction questionnaires and surveys that students complete as a feedback mechanism on their experience. The authors outline the importance of feedback and critique approaches currently taken and set out the aim of the workshop as collecting rich data about student experience

whilst providing students with an engaging experience and introducing them to Design Thinking approaches. Research was undertaken through two 2-day workshops with a total of 59 students of mixed nationalities and degree courses, none of whom had a background in Design Thinking. Working at times on their own and at times in groups, the students engaged in a series of design-led activities identifying both problems and opportunities from their experiences and proposing solutions based on these. A mix of qualitative and quantitative data was collected through a pre-workshop survey, analysis of the activities throughout the workshop and a post-workshop survey. The feedback from the students on the workshop itself was overwhelmingly positive but equally of value is the article's reporting of the use and impact of Design Thinking strategies in producing rich data about a university experience.

The final research article in this issue shifts our focus to higher education and curriculum Instructional Design and, echoing the previous article, taking a design pedagogy/design thinking approach. In *An IDEA for design pedagogy: Devising instructional design in higher education 4.0* Mehmet Ersoy of Eskisehir Osmangazi University, Turkey, makes a case for developing a design approach to Instructional Design in the current context where so much teaching and learning has moved online, speeding up the potential and challenges of Education 4.0 and with a specific focus on pedagogy. Via a brief introduction on pedagogies for e-learning he makes a case for a conectivist approach and, linking this to 21st Century skills with an example from the World Economic Forum makes a further link to a key focus on Industry 4.0. This background forms the context for the development of a conceptual model for Instructional Design that places design pedagogy at the centre. Through his study he analyses literature on design pedagogy including design thinking, instructional design and education 4.0 and draws together links to create a conceptual model for curriculum development and instructional design that includes pedagogical motives, concepts and technologies and stakeholders. The model - Instructional Design for Educational Actuality (IDEA) - is highly detailed, inclusive and ambitious and in the final sections of the article this is recognised by an analysis of implications for current practice alongside a critique that recognises technology's inability to be a solution for everything.

In addition to research articles, this issue also includes a reflection by Derek Jones of The Open University, UK and reviews of two recently updated books.

In *Making little things visible*, Derek Jones reflects on the challenges faced by design and technology educators in 2020 and the ways in which little things taken for granted or that have become tacit have been made visible by the major shift in the ways that teaching and learning have taken place, for example in the absence for many of the pedagogical culture of the physical studio. In addition to reflecting on the past year he highlights the value of capturing and sharing insights and development that have occurred as a result of transitions that have been made, referencing the recent call for articles for a special issue of the journal "*Alternative Studios: Design Education Changes in 2020*" that Derek will guest edit along with his colleague Nicole Lotz.

Finally, we have a review from Andy Mitchell of the recently published 2nd (revised) edition of *Teaching STEM in the Secondary School: Helping teachers meet the challenge* by Frank Banks and David Barlex and from Bhavna Prajapat a review of the recently published 4th (revised) edition of *Learning to Teach Design and Technology in The Secondary School: A Companion to School Experience*, edited by Alison Hardy.

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Reflection: Making little things visible

Derek Jones, The Open University, UK

The response to the coronavirus pandemic of 2020 (Covid-19) will leave a lasting impression on all sectors of education. For design educators especially, the rapid transition from traditional to distance modes of teaching was, and still is, particularly challenging. Design, and especially studio-based education, remain predominantly physically focused and located practices. Moving out of the studio takes away far more than just a space for teaching; so much so, that the initial response to the response to the shift has been compared to that of grief (Brown, 2020).

But what has 2020 revealed about our discipline? About the state of our teaching and learning? About the resilience and legacy of our modes of education? Has the studio, as a fixed space, proven to be impossible to replace? Or will some of the affordances and opportunities experienced become part of future curricula? What does the response say of design education research and knowledge?

Our experiences during 2020 allow a unique opportunity to explore these questions simply because we have all had to confront them in some way. The reflexive nature of our subject has had to be applied to our learning and teaching practices and some of this reflection and learning will be captured in a forthcoming Special Issue in DTEIJ through a special issue and call for papers (see the Journal website for details). The call particularly welcomes insightful reflection on the transitions of the last year and what this might tell us about design education practice and research. In the meantime, this article presents a few observations from the past year.

Things made visible

One thing the crisis did was make certain things visible: things we rarely pay attention to or have taken for granted because they are simply there. Among these are the many events, interactions, connections, and so on, that educators rely on in traditional settings to support teaching and learning: noticing a student's expression of confusion; the serendipity of a student seeing another's work and thinking…; the 'buzz' or 'rhythm' of a shared space as a deadline approaches; the simple act of a shared sketch; etc.

These 'little things', it turns out, are really quite important when it comes to studio as a *mode* of learning, many of which we are either completely unaware of or have so tacitly embodied that we rarely 'see' them at all. The studio provides the affordances and conditions for this range of 'little things' to take place, as has been observed in many studies, whether this is uncertainty and ambiguity (Orr & Shreeve, 2018); sensory affect (Marshalsey, 2017); serendipity (Makri et al., 2014); or even extending our cognition (Radzikowska et al., 2019). Such studies often focus on particular details and provide interesting and unique glimpses of such 'little things'. As design educators, we read about them, nod in agreement, and continue to rely on them taking place daily in our own studios. But we rarely ask how we would recreate

these little things deliberately, or ask what would we do if we no longer had a physical studio to rely on to allow them to emerge?

Historically, design educators have not really had to interrogate such details too closely. As Doblin, quoted in Dilnot (2017), observes, “design was what you did without knowing what you did”, which can be immediately extended to design education: if designers continue to come out of the design education process then it’s working. The nature of tacit knowledge is such that it offers the option to simply be left unexamined on the condition that it continues to be ‘transferred’ and produce the desired results. So, when tacit facilities or affordances are suddenly removed, it’s perhaps unsurprising the disruption is far greater than imagined. If you think that these ‘little things’ are the preserve of traditional design courses moving online, you’d be wrong: at The Open University, UK (OU), we’ve been teaching design at a distance for nearly 50 years (Holden, 2009; Cross & Holden, 2020) and, when we get asked ‘How do you teach design at a distance?’, we also struggle to articulate this directly. Even though our studios are distributed and online, they still rely of a whole range of implicit properties and affordances that we, too, often take for granted. Just as the traditional studio is a complex practicum comprised of ‘little things’, so, too, are successful distance design courses. Writing down such tacit knowledge is exceptionally difficult and, like learning to design, it is perhaps in the application and experience of teaching practice where the knowledge is really ‘stored’ (Jones, 2020). Online and distance design education, as many colleagues have found out over the past year, is at least as complex as its traditional counterpart. So, perhaps it’s time to take these ‘little things’ a bit more seriously, not only in terms of teaching and learning, but also in terms of scholarship and research, where the last year has allowed a way to consider what really matters in design education.

Understanding ‘little things’

Of course, this is where we do have to be careful: comparing traditional, online and distance learning modes is a non-trivial matter. As many colleagues have found out, it is simply not the case that an instructional activity in one mode can be transferred directly to another. For example, having proximate, synchronous time in a physical space does not fully translate to proximate, synchronous online spaces. Whilst some of the properties of these activities might translate well (immediacy of communication, idea representation, etc.), the valuable properties that matter so much to student learning can be far harder to transfer (serendipity, embodied cognition and conceptualisations, social learning and comparison, etc.).

Hence, when moving between traditional and distance settings, it is very often the normally invisible properties and affordances, the ‘little things’, that are the critical and valued components of the learning experience. When these are not recognised and translated appropriately, their omission becomes obvious in terms of outcome, although the cause can remain hard to see. This makes it difficult to directly compare alternative settings and modes of learning without being very careful about what it is we are exploring, as well as acknowledging the conditions and limitations of our inquiry. Very few studies undertake such work appropriately and either fall short of genuine comparison (Broadfoot & Bennett, 2003) or, understandably, do so from an *a priori* favouring of one mode over the other (Han, 2019). More recent work is beginning to address these issues by providing more rigorous comparisons and methods (e.g. Saghafi et al., 2012; Fleischmann, 2019; Jones et al., 2020), but these all face the same challenging basis of comparison. We have no complete definition of studio (Boling et

al., 2016) and some would argue we cannot ever have such a definition (Brandt et al., 2013; Cennamo, 2016), whilst non-designer educators look on in frustration at this 'uncertainty' (Lyon, 2011; McGimpsey, 2011). I would suggest that this is at least in part due to the 'little things' we all take for granted in our tacit practices. The studio, whether physically proximate or online, is the space where we host these little and invisible things and this is strongly linked to the constructivist and student-centred character of studio: it is a place that allows the 'right sorts of opportunities' (Schön, 1987), the 'little things', to emerge in support of learning. What has emerged in this last year, then, is the start of a recognition that it is these underlying affordances, the 'little things', in studio that really matter. Translating and working with these continues to be the real challenge across different modes of learning, a challenge faced by any design educator or researcher. By looking across and between modes of design education, whether distance, blended, augmented, or traditional, we have been given ways of seeing these 'little things' that contribute to, or even make up, the studio. Perhaps in doing so we can start to say some interesting little things about them.

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Long-Term Use of ePortfolios in Craft Education among Elementary School Students: Reflecting the Level and Type of Craft Learning Activities

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Abstract

This paper analyses the longitudinal use of electronic portfolios (hereafter ePortfolios) in craft studies across six years (2013-18). Eight comprehensive school students participated in the study, tracing their craft process activities via photos, narratives, and tapings from the third to the ninth grade. The data involved self-assessment by the learners; peers and teachers were included in the textual content. The data also contained interviews, which were carried out in late spring 2019. The interview focused on students' conceptions of the ePortfolio method and the central elements in constructing it and, finally, improvements of the ePortfolio method. The ePortfolio data was analysed by applying Anderson and Krathwohl's taxonomy for learning, teaching, and assessing. The results revealed that students' knowledge types transformed throughout those years, from versatile to more limited area and students' cognitive process levels, from concrete to more abstract. The interview data supported these interpretations. The interviewees described the changes in their focus when tracing their learning processes; they considered visual and textual content, communication, and metacognitive knowledge as essential elements of ePortfolios. Suggested improvements of the ePortfolio addressed technical issues, platform demands, and practical functionalities.

Keywords

craft education, electronic portfolio, documentation, content analysis, revised learning taxonomy, knowledge creation

Introduction

There is a need for an understanding of comprehensive school students' longitudinal learning processes. Defined in more detail, we need to follow the development of students' skills and reveal the level of learning gained (Atjonen, 2014; FNBE, 2014). This research aimed to study the use of an electronic portfolio (ePortfolio) method to analyse how it promotes the longitudinal learning process and how it fulfils the expectations set for it. Documentation of the craft process and the collected pieces of evidence (photos, narratives, tapings) enable learners to recall and reflect on the learning experiences and hence maintain a much richer and broader view of the craft processes (Barrett, 2007; Keune & Peppler, 2017; Meyer, Abrami, Wade, Aslan & Deault, 2010). The documentation also enables sharing and celebrating achievement, so that learners may enjoy learning, and so that utilisation of recent and prior capabilities are acknowledged for longer. The present study sought to report the results of the exceptionally long ePortfolio study and reveal how the young students experienced working with it. Further,

we aimed to examine students' conceptions of the portfolio and the central aspects of constructing ePortfolios in craft studies. We were also interested in the learners' suggestions for improving ways of working with ePortfolios.

Craft is an obligatory school subject in Finland and guides students to identify design constraints, create ideas, and construct design solutions by using various materials and techniques (Syrjäläinen & Seitamaa-Hakkarainen, 2014). Craft education emphasises multi-materiality and the development of versatile working capabilities (FNBE, 2014). The instructional aim is to develop students' craft-related knowledge and skills and, thus, improve learners' self-esteem, sense of responsibility, and enjoyment (Rönkkö et al., 2016). Craft studies are also expected to advance more generic skills, such as problem solving, thinking, and communication, as well as collaboration and social participation (Pöllänen, 2011). Moreover, the national curriculum for craft education (FNBE, 2014) requires documentation of the learning process at many levels. Documentation is one of the six content areas for every grade and constitutes one of the educational objectives from the third grade upwards. The ePortfolio in craft education appears useful for tracing extended processes of working with various craft projects and products. As a working method, it guides the learner and directs the learning process, enabling formative assessment during the learning process as well as evaluation at the end of it (Saarinen et al., 2019). Furthermore, working with ePortfolios fosters the development of digital competences; mastering digital technologies is one of the seven transversal competences in curricula at all levels of the comprehensive school system and, therefore, it is encouraged to be widely integrated into learning activities in every subject (FNBE, 2014).

We have conducted two earlier ePortfolio studies in craft education. The first study focused on the pupils' user experiences and was carried out after three years of using ePortfolios. The functions and benefits of using ePortfolios in craft education were studied through stimulated-recall interviews. The data was collected from 38 pupils, 25 girls and 16 boys in the sixth grade (Saarinen et al., 2017). The study revealed that pupils identified the key functions (Waltz, 2006) of the ePortfolios, such as collection and management of knowledge, communication, and verification of developmental progress. They were also able to describe the educational benefits of ePortfolio work, such as extending memory, improving digital competences, and learning to organise knowledge. The second study (Saarinen et al., 2019) investigated the content of the ePortfolios across four years. The textual and visual contents were analysed and conceptualised through qualitative content analysis. The study revealed four categories of documentation: process, product, and free and formal reflections (Saarinen et al., 2019). The aim of the present study was to deepen our understanding of comprehensive school students' longitudinal learning processes. We focused on what kind of learning activity and cognitive processes can be found in students' ePortfolios and triangulated the findings with student interviews. Our research questions were as follows:

1. What types of knowledge and cognitive processes did the ePortfolio work contain?
2. How did the contents of ePortfolios change from the early to the later grades?
3. How did students reflect on the changes in various elements, their usage, and improvements of the ePortfolio?

Elements and Maturation of the ePortfolios

Several significant and inspiring development programs (ePearl, Project Zero, Reflect-initiative, Open Portfolio Project, Project e-scape) of portfolio methods have been conducted, and some studies also address ePortfolio working in comprehensive education (Saarinen et al., 2019 and 2017; Nicolaidou, 2013; Barrett, 2007; Moritz & Christie, 2005). The term ePortfolio lacks distinct boundaries and has been defined in various ways: by its process, by its final outcome, and most commonly by its purpose of use (Kimball, 2005; Kimbell, 2012; Carmean & Christie, 2006; Barrett, 2007; Balaban, Divjak & Kopic, 2010). As a working method, the portfolio contains elements that distinguish it from other similar methods, such as completing a task book exercise or writing training. Zubizarreta (2009) points out three central elements of learning portfolios: documentation, reflection, and collaboration. The documentation contains activities of collecting, selecting, and prioritising. Reflection includes analysing and thinking, and collaboration consists of sharing, joining, and communicating (Zubizarreta, 2009). A learning portfolio exists when these elements overlap, but each part can be unequal depending on how it serves the purpose (Zubizarreta, 2009; Corley & Zubizarreta, 2012). According to Kimball (2005), similar elements are present in most portfolio implementations. He crystallises rationales of the ePortfolio pedagogy into four: the process itself giving a deeper picture of the action, multidirectional reflection of the process, the connections with the experiences (coherent sense), and increasing activity of the learner (control and responsibility) (Kimball, 2005).

The implementation of portfolio pedagogy, a chosen system with a chosen tool, is a demanding and multistage process. Love, McKean & Gathercoal (2004) defined the levels of maturation concerning a process to implement both the pedagogy and the electronic webfolio (WBEP). They analysed and categorised eight physical and theoretical qualities related to the use of portfolios (such as type of portfolio, student role, feedback, and heuristic process), six value-oriented issues (e.g., value for student, educator, institution, and digital equity). Furthermore, they identified five levels of maturation of using portfolio platforms: 1) scrapbook, 2) curriculum vitae, 3) collaboration between student and institution, 4) mentoring to mastery, and 5) authentic evidence of learning. These levels are in hierarchical order, containing changes in roles, responsibilities, content, and organisation. The two lowest levels of portfolios could be implemented with paper, ePortfolio or WBEP platforms, and the three highest levels could only be implemented with web-based platforms. The purpose of their model was to provide a conceptual framework for understanding webfolios and to provide guidance for taking the next step to reach new levels (Love et al., 2004; see also Chung, 2010; Challis, 2005).

A Reflective ePortfolio as a Tool for Knowledge Practices

The content of an ePortfolio is dependent on many components: its purpose, the platform used, the available instruction, and especially the practitioner; in other words, the learner and the learner's activity. The ePortfolio method contains designed structured opportunities, which assist students in creating (collecting, selecting, and documenting) their own ePortfolio and reflecting on their experiences. The learner has different interests (for example, with ideological functions), which are served by knowledge (Morrison, 2001). Habermas' (2008) theories of knowledge and human interest examined processes of inquiry through the connection between logical-methodological rules and knowledge-constitutive interests. He divided cognitive interests into three categories: technical, practical, and emancipatory. These

categories contain different kinds of knowledge: instrumental (causal explanation), practical (understanding), and critical (critique, emancipation, and freedom). Furthermore, they answer different questions (knowing what/how/why). This theory has influenced the ideological level of the educational field (Habermas, 2008; Morrison, 2001; Terry, 1997; Quong, 2003).

In the ePortfolio method, the learner collects evidence of experiences, and this way learns new concepts and meanings, which in turn enables further knowledge creation (Bereiter & Scardamalia, 2010). This working with knowledge (with a scale from routine to novelty innovation), individual or social, is called, according to Hakkarainen (2009), knowledge practices. These knowledge practices allow learners to create epistemic artefacts of their activities (Hakkarainen, 2009). An ePortfolio can be seen as one of the epistemic artefacts of knowledge practices. Bereiter and Scardamalia's (2010) requirements of knowledge creation contain five essential criteria to meet: there should be problem solving, shared and longer-lasting (more than the moment) value, a modicum of creativity, and adaptableness to generalisation. General knowledge activities in classrooms could serve as objects or side effects of knowledge creation as such, but the most important function for these activities is enabling further knowledge creation. In reference to Bereiter and Scardamalia's (2010) conclusion, that is a possible way to gain productive knowledge, which means knowledge lived by the learners, worked with it and used it in various ways (Bereiter & Scardamalia, 2010).

Methods

Participants and the Study Setting

The present study took place in an elementary school (grades 1-9) located in a suburb of northern Helsinki, Finland's capital city. Craft education is a common subject for boys and girls. Obligatory craft studies begin in the first grade and finish in the seventh grade. Voluntary craft studies continue further into eighth and ninth grade. All the pupils in this school worked with their own ePortfolio starting from the third grade and ePortfolio was used in this particular school as a support and assessment tool.

An Apple iPad application called Book Creator (non-web-based) was used with young students (from 3rd- 6th grades) and the older grades continued working with Microsoft's web-based platform OneNote. Four iPads (one per group of three to four persons) were available throughout the lessons and the ways of sharing the iPad were agreed within each group. ePortfolios consisted of photos, texts, audios and videos, which were chosen and produced independently by the students. They made decisions independently regarding documentation and content; took photographs, named the content of the image and explained verbally how the process proceeds etc. The teacher defined and reminded to collect personally pivotal events of their working and learning processes. Also, a minimum list of documentation (that covered phases of the holistic craft process) was created by the teacher after the first trial year 2012-2013. The teacher gave feedback related to students' ePortfolios once or twice a month. At the end of every school term the teacher and every pupil individually assessed the school year in the assessment debate and ePortfolio played an important role in this evaluation process. It offered samples of the working processes and advancement of the pupil's understanding but also revealed the weaknesses and limitations of students' documentation and interest to complete the task, just to name a few.

This study focused on ePortfolio data, which was gathered during the years 2013–2018, and students' interview data which was collected in spring 2019. Early years portfolios were stored and dislocated as Portable Document Format (PDF) which is the reason for the disappearance of videos and audios. Other visual data, namely photos, were often general or close-up and challenging to analyse, so the written content appeared to be the most appropriate for research purposes. The written ePortfolio data was selected from the fourth, sixth, and eighth-grade portfolios, and the interviews were organised at the end of the ninth grade (after final evaluation). The content of the learning activities consisted of different craft techniques such as sewing (4th 8th grades), knitting (6th grade), printing (5th, 8th grade) and quilting (4th, 5th grade) and making processes of soft toys (3rd grade), bags (5th grade), clothes 4th, 8th grade) and pieces of art (6th grade) just to name a few. Our study focused on the discretionary sampling of eight students (female), who had six years of experience with ePortfolio usage and were voluntarily willing to participate in the interviews. These students had also chosen craft education as an optional subject. The students of the sampling covered all four documentation categories found in the previous study (Saarinen et al., 2019): the process-oriented, the product-oriented, the free reflection-oriented, and the formal reflection-oriented.

The textual content of the ePortfolios was analysed by theory-driven qualitative content analysis using a summative approach (Hsieh & Shannon, 2005). In the previous study, we had analysed visual data produced by the students separate from the written data but the results revealed congruent emphasis with written content categories (Saarinen et al., 2019): the photos mainly referred to working procedure (see figure 1. below) and therefore our decision was to not analyse isolated contents in this research. The computer program ATLAS.ti was used to analyse the texts which were interpreted to signify an entity of both textual and visual parts. Students' notes were organised in chronological order, and each note was segmented into smaller meaningful units (i.e., the main content of the idea). The length of analysis units varied from one to over 60 words. Altogether, 755 notes were analysed. The coding categories are explicated in more detail in the next section. Figure 1 presents one example of the student's ePortfolio page.

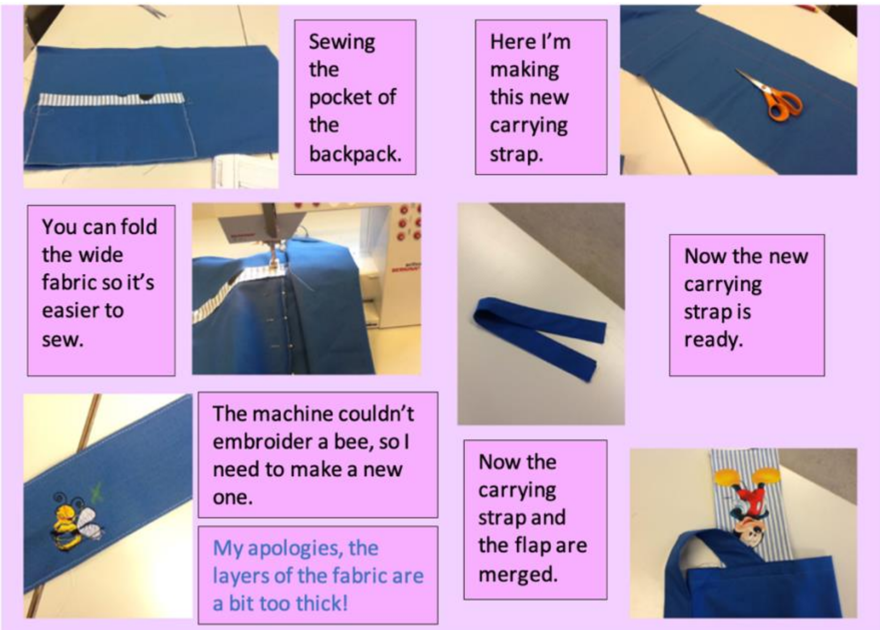

Figure 1. *An Excerpt from a Student Page, with Teacher Comment in Blue*

Thematic semi-structured interviews (Wengraf, 2001) were also conducted, involving three themes: a) perception of the portfolio work, b) changes in practices of working with the portfolio, and c) comparing experiences with different platforms and working styles and providing suggestions to develop the ePortfolio method further. The first theme investigates what essential procedures the ePortfolio method contained. Questions emphasised here include how to work with ePortfolios, what elements are more and less important, and how to guide someone in using the method. The second theme focuses on students' experience and self-observed changes in working throughout these years. They were asked to remember their experiences from the start of using ePortfolios, their experiences after using them for a few years, and their experiences from their last year (grade 8). The last theme challenged students to compare their experiences with different platforms and styles of work and to further develop the method. The interviewer reminded participants of some platform names and helped students remember their working periods with different platforms. Interviews were transcribed and analysed by classifying the responses inductively to the theme groups (approach, changes, and development).

Coding Taxonomy of the Contents of ePortfolios

For the theory-driven content analysis of the ePortfolios' data, we applied the taxonomy developed by Anderson et al. (2001). The applied taxonomy has its roots in Benjamin Bloom et al.'s (1956) *Taxonomy of educational objectives.* Anderson et al. (2001) reorganised and extended the original taxonomy with a few new concepts and with a new dimension and named it *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. The revised taxonomy examines the learner from two different dimensions: the cognitive processes and the knowledge types. The cognitive processes (remember, understand, apply, analyse, evaluate, and create) describe the learner's level of operating in the learning process. According to Krathwohl (2002), these cognitive categories construct a cumulative hierarchy, based on the complexity of the cognitive processes, and there is a continuum from simple to complex processes. The knowledge types (factual, conceptual, procedural, and metacognitive) distinguish the different kinds of knowledge with which the learner is working. The knowledge dimensions, in turn, consist partly of a hierarchy, based on complexity, but also distinguishing factors such as the type of knowledge (Anderson et al., 2001). Amer (2006) has pointed out that the main difference between the original and the revised versions of the taxonomy is how the limitations and weaknesses of the original taxonomy were developed in the revised version and emphasises how the taxonomy benefits pedagogically (see also Wilson, 2016; Pickard, 2007). This taxonomy can be used for many educational purposes: to plan, to control, to assess, and to evaluate both at school and national curriculum levels. The two-dimensional view presents easily what parts are included in the learning process and which are missing, and how well the objectives are mastered (Krathwohl, 2002).

In this study, the Anderson et al. (2001) taxonomy was applied to analyse the content of the ePortfolios fluently. After the first test of data analysis, some categories were merged to better assist the content analysis. Our taxonomy (Table 1) has *three cognitive process* dimensions (the original combined concepts are in blocks): recall (remembering and/or understanding), apply (applying and/or analysing) and evaluate (evaluating and/or creating). The classification highlights the dissimilarities between these categories. The first was declaratory by its nature: a recalling of events that included understanding and was the basic description of one's reality.

The second category was interpretative: more verbose, it covered one's own conceptualisation and the world around him/herself. The third category consisted of evaluation with a creative tendency. It contained a transparent description of the experiences, solving problems and developing a new understanding. Note types are presented with the taxonomy categories in Table 1.

Table 1. The Applied Taxonomy Table with a Short Description of Each Section

Applying Anderson et al. (2001) *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*			**The cognitive process dimension** concrete --------------- abstract --->		
			Recall: **Remember and/or understand**	**Apply:** **Apply and/or analyse**	**Evaluate:** **Evaluating and/or creating**
The knowledge dimension	WHAT?	**Declarative knowledge** **Factual** Bits of information **Conceptual** Organised knowledge forms	**Explains and describes** experience with single or cluster organised knowledge	Uses documentation to highlight own experience, **connecting** assemblies, relevantly like a story of proceedings (naming + connecting)	**Evaluates** based to produced content and develops **uniqueness** of own thinking within the given resources
	HOW?	**Procedural knowledge** How to do something and when to do what?	Recognises, names and uses different methods of working. **Visualises a part** of the procedure.	Connects and organises the parts of the process to construct a quite **flowing narrative** of own experience/s	**Evaluates** the suitability of the **methods** and develops the used methods creatively to reach inventive final result, problem solving
	OWN LEARNING?	**Meta-cognitive knowledge** General and one's own cognition	**Guides** own experience by naming and using different functions and describes own choices, expression of feelings	**Exploits strengths** of own actions to reach the target of flowing story and **ponders the impact** of own action to the final result, expressions of feeling with justification	Develops a novel and original style to create an **individual story** of one's own learning process

The knowledge dimension also had three sections: declarative knowledge (factual and/or conceptual content) and procedural and metacognitive knowledge dimensions, as in the original Anderson et al.'s (2001) taxonomy. These *knowledge dimension* categories were distinctive: declarative knowledge was descriptive and answered the question of what; procedural knowledge based on the activities answered the question of how; metacognitive knowledge covered learners' interpretation of their own learning and action.

In our study, declarative knowledge was largely descriptive and declaratory, naming tools, supplies, and equipment. The notes were generally short—only a few words long—and were often related to photographs by naming the artefact or tool seen in the picture. Descriptions in procedural knowledge were more verbose and contained descriptions of the process retrospectively, concurrently, and prospectively. The content of the note explained what was happening, how the work was going to be done, or what would happen next. In the first recall category, only one event was named and was often expressed with short sentences. In the applied category, the notes contained at least two connected events. The sentences of the note created a narrative-like story of the event described. In the evaluation category, the sentences of the note were fairly long, often including expressions of feelings. The note's content indicated the evaluation or creation of the event. For instance, problem solving was placed in the third category because it consisted of evaluation and creative estimation of the object. The third knowledge dimension refers to metacognitive, which consists of the reflection of one's own action and its impact. Metacognition also consists of naming feelings, sorting out one's

own strengths and developmental targets, reasons for success or failure, or explaining one's own learning solutions in a personal way.

An external researcher tested the inter-coder reliability of the categories for the inter-rater reliability analysis. Two researchers categorised randomly selected samplings of 148 notes (20% of the data, with sample lengths between 1-60 words). Both completed the analysis independently, and the inter-rater reliability was 94.6%.

Results

In this section, we will present the main findings from the first research question: "What type of knowledge and what type of cognitive processes can be revealed in ePortfolios?" We will then describe changes in the quality of the contents in the ePortfolios: What kind of changes can be observed when comparing the contents from the early grades with the contents from the later grades? Finally, we will reveal the results of the students' interviews (RQ3) related to ePortfolio elements, changes in usage of the ePortfolio, and proposals on how to develop the tool and the method. Because of the small number of participants, we did not provide any statistical analysis.

The analysed data consisted of the written notes of eight female students in ePortfolios dating from 2013 to 2018. The total number of analysed words was 12,659, and an average note consisted of about 17 words. The majority of the notes (59%) emphasised procedural knowledge: students described what was happening, how the work was progressing, and what they would do next. This kind of knowledge of working procedures masters justly a subject like craft education, as well as other artistic and practical subjects.

> *We decided that we'll do the highlights out of bias. Lastly, I began to attach the bias to the replacement piece and the old fabric (i.e., shirt). In the next class, I will continue working on it, and I hope that the work will progress better than it did today! (V5)*

The second-largest group of knowledge dimensions was the declarative category, with nearly a quarter of the notes (23%). In this category, students made statements and explained their choices of elements such as design, materials, and tools.

> *Here is the plan I made during the first lesson. On the left is a denim jacket with angel sleeves. There are two versions of the style in the middle. The style at the top has sleeves which are the same fabric as the other parts and is using patterned fabric. In the lower version, the sleeves are the same fabric as the denim jacket, i.e., chiffon or something like that. The upper part on the right is lace and the lower part is made of easily descending and light fabric. I ended up making a denim jacket. (E1)*

The smallest group of knowledge dimensions was metacognitive knowledge (18%, f=92). The students were pondering their learning activities, successes and failures, and the received feedback.

> *It feels like a sort of automation has come over me now! I'm still a bit slow, but when we hold a loop creation contest, I was able to do 21 in 2 minutes. (K6)*

While examining the cognitive process dimension of the notes, it was revealed that the majority of analysed notes, 59%, fell into the recall category and were mainly declaratory in nature.

> *Here's a backpack plan. (H4)*
> *Now there's a pattern on the fabric. (S2)*

A third of the notes placed to the apply category (185/521) and contained more descriptions of craft knowledge and making practices, as well interpretations of the work.

> *The position of the zigzag stitch is so that the other paw is outside the fabric and straight, it is so that both paws are on the fabric. (L7)*

The evaluate category consisted of only 6% (30/521) and was wordier and contained more interpretation than the former category. It also contained statements analysing and evaluating either working processes or decisions.

> *Personally, this part was the hardest for me because the elastic band got lost multiple times inside the sleeve and it was hard to attach the elastic band because the elastic band kept coming out from under the presser foot! (A3)*

These results crystallised the variations of the content used in craft education. There is a need for versatile knowledge types, and naturally, the narratives from the activities change during the different assignments, personalities, inputs, and experiences, to mention just a few relevant perspectives. These kind of student-led ePortfolios contain and reveal large-scale variations of learning outcomes. Despite the variation, learning itself is studied and somehow organized on every level. Therefore, the most important outcome, the learning process itself, is realized and the demonstration of revision and growth is performed.

Developmental Changes in ePortfolios

Next, we analysed developmental changes in the ePortfolio data between different grades. The cognitive process dimension of the recall category was obviously dominant (78%) in the earlier grade (fourth). The apply dimension consisted of approximately 21% of the notes, and the evaluate dimension could hardly be detected (1%) (see Table 2). However, in grade 8, the apply dimension was the largest category, representing over half of the data (55%). The recall category consisted of approximately 32% of the notes, whereas the evaluate dimension had increased to 11%. In turn, the knowledge dimension of procedural knowledge was the major knowledge type in all grades, and declarative as well metacognitive knowledge decreased steadily.

Table 2. Distribution of the Cognitive Process Dimensions and the Knowledge Dimensions in ePortfolios in Grades 4, 6, and 8 (Coloured Categories Represent the Three Highest Frequencies of Every Grade)

		Grade 4			Grade 6			Grade 8			Total frequency
		The Cognitive process dimension									
Knowledge dimension		Recall	Apply	Eva-luate	Recall	Apply	Eva-luate	Recall	Apply	Eva-luate	
	Declarative	36/ 22%	7/ 4%	0/ 0%	43/ 19%	17/ 7%	0/ 0%	9/ 6%	10/ 7%	0/ 0%	122
	Procedural	58/ 36%	16/ 10%	1/ 1%	73/ 33%	40/ 18%	13/ 6%	34/ 24%	56/ 40%	16/ 11%	307
	Meta-cognitive	31/ 19%	12/ 7%	0/ 0%	19/ 8%	15/ 7%	0/ 0%	3/ 2%	12/ 8%	0/ 0%	92
	Frequency	125	35	1	135	72	13	46	78	16	521

When comparing the knowledge dimension between the fourth and eighth grades the change of the highest references can be observed: at first, in grade 4, the knowledge type was decentralised to all three knowledge categories; but in grade 8 the procedural knowledge had clearly the highest frequencies in every cognitive process category. This result was expected because of the nature of craft education: the design and making process is a key element, and "learning by doing" is a focal activity. Also, the change from using declaratory communication to a more verbal, individual, process-oriented interpretation of the action shows how the students can use more subject knowledge and combine the content learned with their own action and to their own story—not just naming or recalling things, which itself is also one of the aims of craft learning. Moreover, to analyse and evaluate one's own work requires practice and guidance and is therefore understandable as being achieved and performed in the higher grades. Further, the evaluation of learning was implemented with different applications (in grades 6 and 8), and therefore it decreased significantly. These findings showed that the knowledge content was more versatile in the fourth grade than in the eighth grade. The highest knowledge frequencies in the eighth grade concentrated strongly on the procedural dimension and the cognitive process dimension on the apply section, and the contrast became more versatile in the eighth grade compared to the fourth-grade recall category. This change was also expressed by the students during the interviews. They explained that things they did in the lower grades, like discussing their feelings and thoughts about their learning, were not in focus anymore during the later grades. They felt that it was more important to write a more professional report of things they had done than to ponder their own perceptions.

The results of the cognitive processes in the present study indicated that the concrete (cognitive process) skills (recall) dominated among younger students when compared to the more abstract skills (apply and evaluate). The results with the data revealed that there were some changes in student work throughout the years. At the beginning of using the ePortfolio method (fourth grade), the content consisted of versatile pieces of knowledge compared to the higher grades (sixth and eighth). However, the elements of documentation in the fourth grade were seldom combined and did not contain an interpretation of the students' action, although emotions were more often processed. However, a clear personal trace and a critical attitude were still missing in the highest grade. It is good to note that craft education, as well as the

assessment of it, strongly emphasises the craft processes themselves, which could influence students' documentation during their studies.

Results of the Students' Interviews

In the interviews, the usage of the ePortfolio focused on how students perceived this working method. Interviewees highlighted the working method by explaining what one could do and how they should do it and also raised the concept of students' action (i.e. accurately proceeding from start to end) and things to be added to ePortfolios (i.e. feelings and communication). As an important element, interviewees further named such as telling "step by step," guidance on how to use the platform, and the teacher's active role in communication. Understanding one's own work was highlighted as well; two students stated that the whole documented content is the most important thing.

> *Let's write what happened as if to clarify and then it when it becomes such a good whole that how such a conclusion has been reached. (K6)*

The importance of the method was emphasised in showing their development, and the ePortfolio was considered important in supporting their memory and their successful assessment.

> *Even the teacher sees better what has been done when there are many students, so it is easier to see from the portfolio what has really happened and then it is also good for you to remember what has been done. (S2)*

> *I have noticed that it helps to outline all the different stages of work and it can help to get a better overall picture. (V5)*

> *Then it helps the teacher and the students in life and in assessment. (A3)*

For weaknesses of the method, they mentioned time consumption, interruption of flow when working, and some technical problems (battery, loading).

> *Just that even if you get into some good flow on the job, so that you can do that job for a really long time, then you have to remember to stop in between and take that picture and put it there so that you don't forget about them. (Q6)*

There were similarities between students when they were describing the changes in their work. They described that the focus of the documentation had changed. During the first years, they paid more attention to external factors like visual representations (colours, for example), partly playing with funny decorations; but later they learned to take better documentary pictures and briefly explain their work in progress. In other words, they learn to do documentation more systematically and accurately.

> *Then there might have been a bit of a fumble and most of all I didn't pay attention to the appearance of the thing that was just those colours and such and then afterwards have learned to take as illustrative pictures as possible and write short and concise texts. (L7)*

They also emphasised the importance of the content and how they learned to document in a more “professional way” through detailed photos, more explanations, and no childish decorations. They also explained how they focused more deeply on working, learning, and trying to use the right craft concepts. Some students explained how they learned to edit pages and work in a more logical order. Other students emphasised how they learned to use ePortfolio as a part of their learning, not just for having fun.

> *So it really started to take the kind of thing that quite rightly illustrated it in its own work and in a way used it as part of learning and not just the silence that you can make such funny texts and take nice pictures here. (S8)*

The students’ suggestions for improvements to the ePortfolio were divided into three themes: technical issues, platform demands, and practical functionalities. The technical issues were related issues like battery charge and a suitable quantity of equipment. The platform demands were more general issues, like being easy to access, use, or import data to; or wishes for a book-shaped format. These wishes on how to improve the platform would need a more detailed description of the desired changes to be able to concretely develop the platform to be more user-friendly (for example, signing in or adding elements).

> *It had to be functional… what we had in primary school was functional, you got access to it so quickly, but the only thing was that there were several students at the same end so there was sometimes a wait and then what was online application, so it was difficult to transfer pictures, that is, when you had to go to a computer, and it took time to log in. (E1)*

The practical functionalities contained knowledge of user experiences, which could be easily implemented in everyday practices. Participants wished to have their own time for ePortfolio work, for example, at the start or end of each lesson. They also wished to have closer communication with the teacher; for example, the teacher would read the ePortfolio every week and comment on their processes.

> *You can write a bit like something for the next lesson, that at the beginning of the lesson you could always read what is the next task or some tips that if at the beginning of the lesson everything covers the portfolios and then you have written there that the heel of the wool sock or the hem something like that might get started more easily when you can sometimes be there and you have no idea what you should do. (H4)*

Discussion

The aim of this research was to fulfil the need to follow the students’ longitudinal learning processes and, through the analysis of knowledge and cognitive processes, reveal how their use of ePortfolios has changed during their six years of craft studies. The topic and the data in this study are unique, and overall, studies of sustained use of ePortfolios with young students are rather unusual. Significant development projects and programs exist (ePearl, Project Zero, Reflect-initiative, Open Portfolio Project, Project e-scape), but more research, especially long-lasting and young students learning-centred process data, is needed (Meyer et al., 2010; Carney, 2006).

The results of the present study indicated that the concrete cognitive process skills (recall) dominated among younger students when compared to the more abstract skills (apply and evaluate). However, when analysing the data in a class-based setting, some transition toward more abstract cognitive categories could be detected. Anderson et al.’s (2001) revised taxonomy has been framed for lifelong learning, and could be the reason why the results of this study emphasised the upstream categories (recall and apply). The transition of the focus toward more abstract cognitive processes can result both from the increased learner experiences and their age. The interview data also confirmed the trend toward highlighting the craft process more than reflecting other elements of the learning activity. The craft education, as well as its assessment, highlights the craft processes (Syrjäläinen & Seitamaa-Hakkarainen, 2014) that could have influenced students’ observations and documentation during their studies. Still, other objectives (Rönkkö et al., 2016; Pöllänen, 2011) such as communication, social participation, and enjoyment were also observed.

The ePortfolio types (Kimbell, 2012) determined the three different contents: storage (student as storer), rapport (student as reporter) and dialogue (student as thinker). This division has similarities with Habermas’ (2008) three-tier model of interest: technical interest (knowing what, contains no challenge and things accepted as they are), procedural interest (knowing how, contains a wider picture with more interpretation and therefore more led by the individual), and emancipation/critique interest (knowing why, contains all the described levels plus a critical, distinctive imprint on one’s own viewpoints). Introduced levels also have similarities with Andersson et al.’s (2001) taxonomies. This kind of transition could be observed from the results of this study: in the eighth grade, the students paid more attention to procedural knowledge, but rising to the highest level demands more mature cognitive development and is seldom found in the output of young learners.

When classifying the three types of ePortfolio, Kimbell (2012) explained the differences based on reflection and working. Figure 2 gathers the process of the ePortfolio with its elements, different ePortfolio types and development levels of the learner, and seeks to clarify understanding of the ePortfolio method in craft education as well as adapted to other subjects. These changes can be described by using the elevator metaphor (see Figure 2) that can be affected by the variation of the ePortfolio type. The other elevator is the degree of freedom, where students are closely guided at the beginning of the process, and in time get more responsibility. The background thoughts of the elevator metaphor were applied from Habermas’ theories of knowledge and human interests and philosophy of emancipation (Habermas, 2008) as well as from Love et al.’s (2004) levels of maturation theory. The elements of the ePortfolio are connected from Zubizarreta’s (2009) model, The Learning Portfolio.

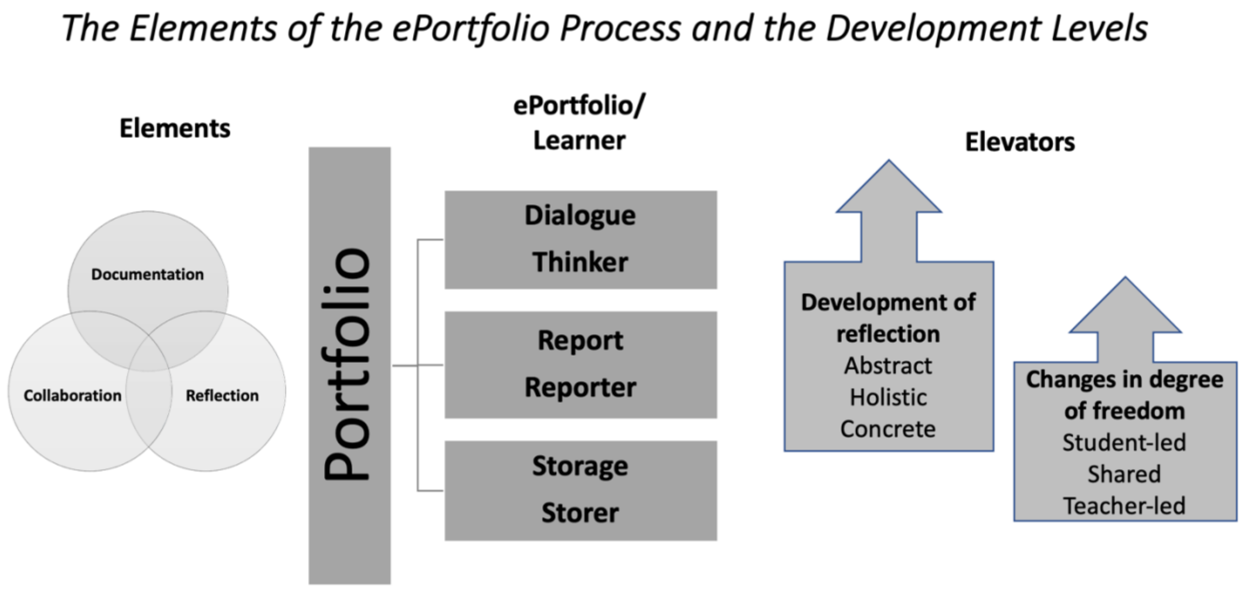

Figure 2. The fusion of ePortfolio theory and practice

The ePortfolio method as such elicited pleased experiences among the interviewed students, giving a more versatile picture of the learning process, as Keune and Peppler (2017), Meyer (2010), and Barrett (2007) have highlighted. Chen and Black's (2010) concept of "folio thinking" could be detected from the interview data: students outlined the importance of the process, reflection, and their own role in creating the ePortfolio, as Kimball (2005) has stated. The improvements that students discussed showed a critical attitude towards the ePortfolio method. Students suggested, for example, a stronger connection with the curriculum (plain periods) and closer communication with the teacher (mentoring).

Students' reflections gathered understandably around the process and procedural knowledge. That knowledge could be interpreted in terms of Bereiter and Scardamalia's (2010) concept of productive knowledge. The data confirmed how the students worked with the knowledge and the knowledge lived by the learners—they got their own interpretation to the level a comprehensive school student reached. The section of knowledge creation (Bereiter & Scardamalia, 2010) could also be traced from the data. Some situations demanded problem solving with a modicum of creativity to be able to proceed with assignments smoothly.

Our study had several limitations. The study was conducted in one of the researcher's schools with the students she had worked with during the data collection period. Familiarity should be taken into consideration, as well as the modest size of the chosen sample. Eight participants were voluntarily willing to give their ePortfolios to researchers and were also voluntarily willing to participate in the interview. The participants were all female and belonged to a group which had positive attitudes towards school and assignments. Furthermore nearly all of them performed well in all school subjects. These students were interested in the crafts (had chosen it as an optional subject) and in crafts in general and were willing to develop their own understanding of the topics. A positive attitude could enrich and add diversity to the data. An engaged student could be more active, could analyse more eagerly and could be more competent to verbalize reflections in their ePortfolios as well as in interviews. Craft education

was the only subject that used the ePortfolio method in the studied school at the beginning of the data collection period, but later also other school subjects started to use it more frequently. This could have positively influenced students' active participation in the early years of the data collection.

Nevertheless, this study was a serious trial run to discover how students, while working, can perceive and save their learning processes individually in action with the help of technology. In the future, we need to develop different methods and data collection models to be able to discover learners' inner qualities in educational context, as Seery et al. (2019) stated. Our challenge in craft education is also to regain a more balanced situation with the stages of craft process and product focus: to bring ideation and design to the foreground along with the dominant making stage, and to revise the importance of the final product. ePortfolio and process documentation could be one way to enable the above mentioned development. Technology still plays a meaningful role in the discussion of ePortfolio use now and in the future. According to Carney (2006), these technology-enhanced knowledge practices need to be studied carefully to be able to show what the electronic method has to offer learning (Hakkarainen, 2009) and what are the effective methods for studying it (San Jose, 2014). Carney (2006) names five recommendations for future studies: grounding research in theory, clarifying the role of technology and the contribution of the studied methods, retaining the richness of the ePortfolio, and increasing large-scale and long-term research. Our study contributed a few pages in the context of craft education, but these topics need to be further researched in the future.

Acknowledgements
The present project is partly funded by the Academy of Finland: Co4Lab 12863837 and Growing Mind 1312527.

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Investigative activity in pre-primary technology education—The Power Creatures project

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Abstract
The present study explored pre-primary students' investigative activity during a longitudinal, integrative technology education project: the Power Creatures project. Investigative activity refers to the way young children act in a learning context that combines inquiry-based activities with creative hands-on activities, such as designing and crafting. Nineteen pre-primary students (aged five to six years) and two teachers participated in the case study. The main data set consisted of six video-recorded small-group sessions in which the children experimented with electronics and designed and made felted creatures containing soft circuits. The data were analysed using a theory-based, deductive content analysis. The results indicate that playful, investigative activities support pre-primary students' learning of everyday technologies and that children can transfer their understanding of the technological process from one situation to another. This process requires careful pedagogical planning and scaffolding that maintains the longitudinal process and adapts to its established and evolving goals.

Keywords
pre-primary education, technology education, investigative activity, STEAM, craft education, child-centred pedagogy

Introduction
Starting from a very young age, technology plays a significant role in children's lives. Therefore, in recent years, technology education has been emphasised as important in the early years of education curricula (Fleer, 2011; Marsh, 2016; Sundqvist & Nilsson, 2018). Early childhood is a period in which the foundation for effective and enduring learning is built (Mawson, 2010; Turja, Endepohls-Ulpe & Chatoney, 2009). The purpose of technology education is to help children understand everyday technology and how it can be used to solve daily life problems (Fox-Turnbull, 2019; Sundqvist & Nilsson, 2018). Here, children are encouraged to observe a technological environment in which they learn to compare, classify and organise the information acquired through observations or measurements, hence supporting their growth as thinkers and learners. At the essence of young children's technology education is emphasising human activity, innovative solutions, and inquiry-based and experimental activities, not technical devices (FNBE, 2016; Kilbrink, Bjurulf, Blomberg, Heidkamp & Hollsten, 2014). Learning goals should have significant overlaps with scientific, engineering and design practices, as well as crosscutting concepts (Quinn & Bell, 2013).

In the present research, we situate pre-primary technology education within the integrative STEAM (science, technology, engineering, arts, and mathematics) approach (e.g., Bequette & Bequette, 2012). In STEAM, the 'A' refers to not only arts but also design and humanities (Daugherty, 2013), shifting the focus from technology as applied science towards more

multidisciplinary and creative problem solving (Jones, Buntting & de Vries, 2013; Williams, 2012). This shift has been fuelled by the need to educate—starting from early stages of education—future citizens who can understand, critically reflect and creatively influence the technological world (Ge, Ifenthaler & Spector, 2015). The integrative and future-oriented approach to technology education is also emphasised in the Finnish National Core Curriculum for pre-primary education (FNBE, 2016). The curriculum highlights encouraging children's interest in science and technology, creative designing and making, problem solving, examining and experimenting with structures and materials, and reflection on the processes and products. According to the curriculum, all competences are approached and learned in integrative ways.

We present a longitudinal STEAM project, the Power Creatures project, where pre-primary students explored electricity as a phenomenon and designed and constructed felted toys containing soft circuits (Yliverronen, Rönkkö, & Kangas, in press). The main aims of the project were to familiarise children with everyday technologies, especially electronics, to practice inquiry-based and creative hands-on activities and to support children's self-confidence and self-esteem. Following the guidelines of the curriculum (FNBE, 2016), the project emphasised child-centred pedagogy and playful elements, along with various technology-related, hands-on activities. In child-centred practices, children are viewed as active knowledge constructors, and the adult's main role is mainly to facilitate this by providing guidance, opportunities and encouragement (Cremin, Glauert, Craft, Compton, & Stylianidou, 2015; Lerkkanen et al., 2016). In the project, hands-on activities involving designing were seen as powerful vehicles for teaching STEAM content (see Lindeman, Jabot & Berkley, 2014; Park, Byun, Sim, Han, & Baek, 2016) because these activities encourage experiential learning, especially when learning is integrated and not too subject oriented (Bennett & Monahan, 2013; Honey & Karter, 2013). Furthermore, the STEAM approach was seen as an effective way to teach young students creative technological competencies (Ghanbari, 2015; Lindeman et al., 2014).

In the present study, we use the term *investigative activity* to describe the way young children act in the context of working on a project involving both inquiry-based and creative hands-on activities (Yliverronen, Marjanen & Seitamaa-Hakkarainen, 2018). Investigative activity refers to a process in which young children craft, design, apply technology and learn science, integrating several objectives of early years education in a child-centred way. Our aim is to examine how pre-primary students' learning of everyday technologies can be supported with investigative activities. We addressed the following research questions:

1. What is the nature of pre-primary students' investigative activities in a STEAM project focusing on everyday technologies?
2. What types of pedagogical practices support pre-primary students' investigative activities during a longitudinal STEAM project?

The current paper is organised as follows: First, we will discuss inquiry-based and creative activities in pre-primary education and present Stylianidou et al.'s (2018) theoretical framework that summarised the pedagogical synergies found in both approaches. Then, we will consider the role of hands-on design and craft activities in early years technology education. In the methods section, we will explain how we adapted the framework for exploring pre-primary students' investigative activities. Finally, we will present the findings and conclusions.

Inquiry-based and creative hands-on activities as vehicles for STEAM learning

Pre-primary education is an important period in children's lives, offering them opportunities to be inspired by various fields, to experiment and to learn new things. When learning activities are connected to children's experiences, they have the opportunities to imagine, explore, experiment, ponder and recognise various phenomena. Research on early years education highlights the affective dimension, such as being imaginative and innovative and creating the possibility for question-posing, self-determination (e.g., Craft, McConnon & Matthews, 2012) and playful experiences (e.g., Larsson & Halldén, 2010) as necessary conditions for learning because they nurture children's motivation to understand the world. Fascination and wonder can trigger engagement and curiosity, leading to the use of inquiry practices to develop explanations for phenomena (Milne, 2010). By engaging in inquiry (i.e., the processes of observing, questioning, predicting and evaluating), young children learn how to construct knowledge, particularly when guided and encouraged by adults (Hollingsworth & Vandermaas-Peeler, 2017).

Combining inquiry-based learning with creative activities in early childhood education has been emphasised in several studies, especially in relation to science education. Through an extensive review of policy-related and research-based literature, Stylianidou et al. (2018) created a conceptual framework of eight common pedagogical synergies that run between inquiry-based and creative approaches in early years science education: 1) play and exploration, 2) motivation and affect, 3) dialogue and collaboration, 4) problem solving and agency, 5) questioning and curiosity, 6) reflection and reasoning, 7) teacher scaffolding and involvement and 8) assessment for learning. These synergies highlight that both inquiry-based and creative approaches can be employed as tools for developing knowledge creation and learning, and both offer motivational support for promoting positive attitudes about science and creative ways of working (Stylianidou et al., 2018). Moreover, children's exploratory and investigative engagement have been both recognised as being important for furthering young students' creativity and science education and their consideration of ideas and concepts (Cremin et al., 2015).

The first pedagogical synergy, *playful exploration*, is inherent in all young children's activities (Stylianidou et al., 2018). Activities with inventive and experimental elements allow children to act in a way that is natural for their age: learning by exploring, doing and playing. Pre-primary technology education needs the space for imaginative play and playful elements along with more goal-oriented activities (Yliverronen et al., 2018). Research, interpretation and imagination together develop children's competencies broadly: play is a key element in young children's learning processes (FNBE, 2016; Lindqvist, 2003; Vygotsky, 1978). Furthermore, narratives have been shown to engage children's imaginations and foster their creativity (Cremin et al., 2015). *Motivation and affect* underline the role of aesthetic engagement in promoting children's affective and emotional responses to various learning activities (e.g., Craft et al., 2012). *Dialogue and collaboration* support learning in many ways, such as fostering a deep understanding (e.g., Sawyer, 2006). They enable young children to externalise, share and develop their thinking and verbal reasoning skills (e.g., Alexander, 2020; Fox-Turnbull, 2019; Mercer & Littleton, 2007). Discussion and the sharing of ideas and ways of thinking develop increased awareness, which can improve one's own ideas (Cremin et al., 2015).

Problem solving and agency, as well as *questioning and curiosity,* are at the core of inquiry-based and creative activities; the emphasis on children's own questions and investigations is fundamental. Open-ended investigations do not have a predetermined outcome: unrestricted starting points lead to a variety of solutions and support children's creativity (Driscoll, Lambirth & Roden, 2015). Chappel, Craft, Burnard & Cremin (2008) argued that creative teachers often employ open-ended questions and promote speculation by modelling their own curiosity. However, if young children have little experience with open questions, they may find them difficult (Harris & Williams, 2007). In addition to discussions, children's curiosity and questions may be expressed through drawings, gestures, working with materials and play (Wood & Hall, 2011). Research (e.g., Craft et al., 2012; Cremin et al., 2015) has shown that young children's engagement in identifying their own problems is central to creativity, and teachers' interest in and respect for children's questions facilitate the children's sense of autonomy and agency as learners. Engagement with problems fosters a child's ownership of learning, decision making and self-determination. Through a scaffolded learning environment, children can be provided with shared and meaningful experiences and develop their creativity, as well as formulate questions and ideas about relevant concepts.

The activities of *reflection and reasoning* underline the importance of metacognitive processes, reflective awareness and deliberate control of cognitive activities (Stylianidou et al., 2018). In early years education, these abilities are still developing, and teachers' sensitivity to children's needs plays a central role in working with young learners (Fleer, 2000). Teacher *scaffolding and involvement* often occurs in practical situations, but it also occurs when a teacher scaffolds children's thinking between everyday experiences and more formal scientific concepts. This process involves teaching thinking skills, which help foster children's independence as problem solvers (Bodrova & Leong, 2012). The last pedagogical synergy in Stylianidou et al.'s (2018) conceptual framework is *assessment,* which refers to the formative assessments of children's skills, attitudes, knowledge and understandings.

In the present study, we employ Stylianidou et al.'s (2018) framework in the context of STEAM-based technology education, where inquiry-based activities were combined with creative hands-on activities. Young children's technology education should be a place that fosters children's imagination and playfulness (Fleer, 2000). Children have an inner capacity to imagine, invent and create, giving them the potential to learn many ideas from concrete hands-on experiences (Turja et al., 2009). Integrating technology education with hands-on design and craft education is a logical approach because these learning areas have common objectives and procedures: children are encouraged to discover, construct projects out of various materials and resolve and describe the technological problems they have encountered (Yliverronen et al., 2018). The implementation of hands-on activities requires learners to practice multiple competencies, such as participation, collaborative problem solving, investigation, explanations and arguments that are personally relevant and related to their lives. Through design and hands-on activities, learners can identify a problem or need, solve various subproblems, consider various options for a design and test and implement their own ideas (Fox-Turnbull, 2019). Design-based activities can be inherently motivating for children because most children are interested in making things, and through design, they have the opportunity to engage in independent decision making concerning their own work (Bennett & Monahan, 2013).

Method

The present qualitative case study took place in a public kindergarten's pre-primary group in a western Finland urban area during the 2019 autumn term from September to December; the project comprised 20 sessions over a period of four months. A total of 19 pre-primary students (9 girls and 10 boys) who were aged five to six years and two teachers participated in the longitudinal Power Creatures project. During the working sessions, the whole group was divided into groups of six or seven children to ensure a safe work environment and sufficient adult support.

The empirical data consisted of six video-recorded small-group sessions, including children's hands-on activities and experimentation with electronics. These six sessions were selected to give an accurate description of the children's and teachers' activities at various stages of the project. This amount of data enabled us to conduct an analysis that was fine-grained enough to reveal detailed activities without losing the overall view of the project. The video recordings were made in two learning spaces as the children progressed in the project at varying paces. The rich and dense data were obtained with GoPro cameras attached to the children's heads. As additional data, field documentation (notes and photos) collected by the project assistant and researcher, as well as children's sketches and finished Power Creatures, were used. The same data were analysed in our previous study (Yliverronen et al., in press), in which we examined the implementation of the project and the teachers' supporting activities on a general level.

Table 1. The framework for analysing the Power Creatures project (adapted from Stylianidou et al., 2018)

RQ1. The nature of children's investigative activities	**Inquiry-based and creative approaches**	**RQ2. The types of supporting pedagogical practices**
Inquiry-based and creative hands-on activities	Play and exploration	Teacher scaffolding and involvement
	Motivation and affect	
	Dialogue and collaboration	
	Problem solving and agency	
	Questioning and curiosity	
	Reflection, reasoning and assessment	

In the present study, we analysed the data using a theory-based, deductive content analysis method (see Elo & Kyngäs, 2008). For the analysis, we adapted Stylianidou et al.'s (2018) framework of the common pedagogical synergies between inquiry-based and creative approaches in early years science education, identifying a) the children's investigative activities and b) the supporting pedagogical practices within each theme of the framework (see Table 1). Stylianidou et al.'s (2018) themes *reflection and reasoning* and *assessment for learning* were combined because during hands-on activities, the constant interaction of thinking and doing is pivotal (see Kimbell, 1994), and the evaluation of the process, instead of the end result, is underlined. The theory-based framework helped us conceptualise the empirical data and understand how pre-primary students' learning of everyday technologies could be supported with investigative activities.

Findings

Overview of the Power Creatures project

The aim of the present study was to analyse the nature of children's investigative activities and their pedagogical support during the integrative Power Creatures project, which focused on everyday technologies. The project phases and the teachers' and children's activities are presented in Table 2 within the framework of inquiry-based and creative approaches.
The Power Creatures project consisted of six phases, together forming a holistic process. The process involved exploring one's own strengths, an inquiry-based, playful orientation and studying of electricity, designing and making Power Creatures with soft circuits and evaluation of the whole process. The project included various investigative activities, which were supported by the teachers' scaffolding, as well as with the involvement of parents, grandparents and older students. In the following, we present more detailed findings, first regarding the children's investigative activities and, second, regarding the supporting pedagogical practices.

Table 2. The Power Creatures project phases and the teacher's and children's activities within the framework of inquiry-based and creative approaches

Project phase (total of 20 lessons)	**Teacher scaffolding and involvement**	**Children's investigative activities**	**Inquiry-based and creative approaches**
Exploring one's own strengths September (3 lessons)	Evoking children's interest and motivation, hearing their thoughts	- Discussing the themes of self-esteem and self-confidence - Finding their own strengths - Making a power poster	**Motivation and affect**
Orientation to electricity October (2 lessons)	Arousing curiosity and guiding thinking with relevant questions, discussions, and tasks	- Wondering about electricity as a phenomenon -Performing experiments from a children's electricity book	**Questioning and curiosity**
Studying circuits November (2 lessons)	Enabling playful exploration and child-centred activities related to circuits and conductive materials	- Playing an embodied 'Circuit play' - Testing different conductive or nonconductive materials	**Play and exploration**
Designing the Power Creatures November (5 lessons)	Supporting engagement, imagination and development of understanding with an open-ended design and making task	- Drawing the Power Creatures depicting their strengths - Making patterns - Designing the soft circuit and the placement of its components	**Problem solving and agency**
Making the Power Creatures November (5 lessons)	Enabling meaningful collaborative craft process with older students and parents	- Felting the basis of the Power Creature - Cutting the felt - Needle felting the details - Testing and sewing the soft circuits	**Dialogue and collaboration**
Evaluation of the process December (3 lessons)	Fostering awareness of one's own thinking and learning, encouraging self-reflection and reasoning	- Self- and peer-evaluation during the process - Telling stories about the creatures - Producing and staffing an exhibition of the Power Creatures	**Reflection, reasoning and assessment**

The nature of children's investigative activities

Because one of the goals of the project was to support children's self-confidence, the project began with activities related to this theme. The children's *motivation and affect* were evoked through an exploration of their own strengths—or their 'powers'. Children got to know 'Molli', a creature from a picture book by the Finnish author Katri Kirkkopelto. Molli is a small and angry character who lives alone in the middle of a big garden. Molli dreams of having a friend to share secrets, sit quietly together and play with. The teacher also read aloud Avril McDonald's picture book *The Wolf and the Shadow Monster*, which is designed to help children explore

emotional intelligence and deal with confidence issues, such as managing anxiety and fears. The children discussed both of the books' themes with their teachers and played games related to them. Based on these activities, the children created their 'power posters', illustrating the strengths they considered to be important.

Another focal theme in the project was everyday technology, particularly electricity. Because the children did not know electricity as a phenomenon, their *curiosity and questioning* about the theme was evoked through wondering. Together with the teacher, the children pondered their everyday observations related to electricity and considered questions such as what would people do if there was no electricity. They also performed some tasks from *The Electricity Book of Little John*; this book was published by The Finnish Association for Electrical Safety and has several stories that reflect on the nature and development of technology with a playful approach. The idea is that children reflect on the stories and carry out the same tasks as Little John. At the same time, they learn about electrical safety. The book motivates children to explore everyday things, aiming to evoke their investigative attitude and own questions.
After these orienting activities, the children further studied electricity through *play and exploration* around the theme of circuits. At first, the children played a game called 'Circuit play', where they held each other's hands and tested how a message or impulse is transmitted. In the game, one child acted as a switch and sent an impulse. Another child was a buzzer, which rang when the impulse arrived. A third child acted like a battery, and the rest of the children were conducting bodies. This provided the children with the initial concept of a circuit, which helped them when the idea of this play was then transformed into a task with actual components—see Figures 1 and 2.

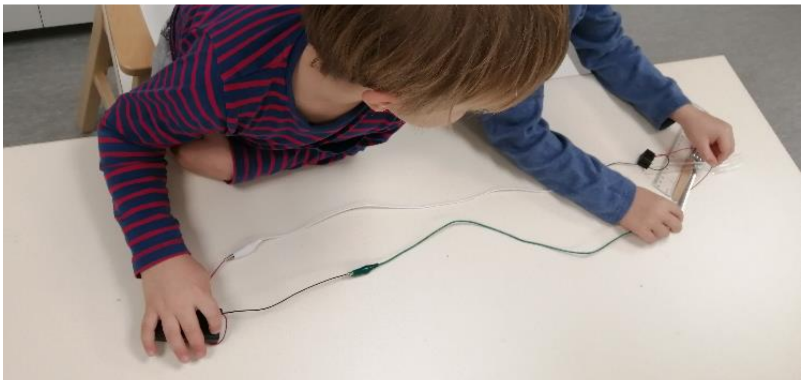

Figure 1. Children testing a circuit with forks

The children worked in pairs and constructed a circuit with alligator clips (resembling the holding of hands in the game 'Circuit play'), a battery and battery holder (like the child who acted as a battery), a buzzer (like the child who acted as a buzzer, making a sound indicating the arriving impulse) and any materials they could find in their surroundings. If a material conducted electricity, the buzzer rang. For example, a metal fork in the circuit made the buzzer ring, but a plastic box did not. The children expressed joy with excited whoops, exclaiming, 'It works!'

Figure 2. Children investigating whether the door handle conducts electricity

Children's imagination can be supported by giving them open-ended tasks, which require creative *problem solving and agency*. Here, the task was to design and make a Power Creature, a felted toy with a soft circuit. The task integrated the previous phases of the project because the aim was to develop children's emotional skills and self-esteem and support their understanding of electricity through creative design and craft activities. The children pondered their own character traits, shared their strengths with each other and designed a Power Creature by drawing. According to their drawings, the children also drew patterns to outline the shape of the soft toy and understand the amount of material needed for felting. In addition, they designed the soft circuits included in the creatures, as well as the placement of electrical components, such as LED lights for eyes or other details. Their understanding of the function of a circuit was clearly visible in these drawings, which can be seen as the first stage towards drawing a proper circuit diagram.

In the Power Creatures project, in addition to interacting with each other and with the teachers, the children also had *dialogue and collaboration* with their parents and older students. During the making phase, the children felted the wool pieces for their creatures. With a little help from their parents during a parents' evening at the preschool, the children were able to make both the front and back pieces by using soap, warm water and abrasion. Together with Grade 4 school students (aged 9–10) who visited from a nearby school, the children felted some extra pieces for the creatures (Figure 3). After making additional pieces for both the front and back, the children cut the pieces according to their patterns and added details with needle felting.

Figure 3. Collaborative felting

In the next phase, Grade 8 students (aged 13–14) helped the children sew the soft circuits into the creatures using conductive thread, a coin battery holder and an LED light. Together, they first checked whether the circuit designed by the pre-primary student worked, and then, they sewed both pieces of the creature together. The finished Power Creatures were visible evidence of the children's knowledge created through embodied and materially mediated means; through them, both the children and adults were able to see what was accomplished during the project (Figure 4). The children were happy with their creatures and played with them eagerly.

Figure 4. Power Creature with a soft circuit that was tested and sewn in

Reflection, reasoning and assessment took place throughout the project, and several methods were used. The children reflected on their own actions through self-assessment, told stories about their creatures and gave feedback to each other. An assessment connected to crafting refers to the self-evaluation of the whole process, including the designing and making phases, as well as the ready-made product. As the 'grand finale' of the Power Creatures project, the teachers and children organised an exhibition of the creatures for parents, grandparents and older students. The aim was to provide the children with the opportunity to get feedback from relatives and older students and support them in reviewing the whole project through story crafting. However, the Power Creatures project, which lasted the entire semester and included 20 lessons in total, was challenging and demanding for the children and their teachers. In the end, the exhibition became an occasion to show the end results of the project, not an opportunity for reflection and reasoning focused on the process behind them. Story crafting was not implemented as planned because the children were too excited about the exhibition to focus on reviewing the months preceding it. Nevertheless, planning and organising the exhibition provided the children with opportunities to reflect on the project, even though this was not systematically utilised.

Pedagogical practices supporting children's investigative activities

Our second research question focused on the pedagogical practices that supported the children's investigative activities during the Power Creatures project. The longitudinal project included several dimensions and pedagogical choices as the children engaged in various investigative activities. Here, it was crucial to provide the children with timely scaffolding throughout the process. Aside from the teachers, parents, grandparents and older students were also involved in the project; however, only the teachers were responsible for meeting both the short- and long-term goals of the project. This required careful pedagogical planning both before and during the process, not only thinking in advance about the various steps of the project, but also responding to the moment-to-moment situations that arose in the classroom. All in all, very sensitive scaffolding and involvement was needed from the teachers to listen and employ the children's ideas and support the children's own thinking and acting. Carefully selected books, along with discussions and tasks based on them, were used to evoke children's *motivation and affect* towards the project themes. The teachers employed the pedagogical ideas in the books, such as guiding the children to draw a 'power poster' to support and develop their emotional skills and self-regulation.

The children's *curiosity and questions* about everyday technology were evoked with a discussion about electricity. The children did not know about electricity as a phenomenon, so their interest was aroused by asking questions about their everyday observations:

> *Let's imagine we don't have electricity now. What would we do? How would we survive at pre-primary school and at home? What things can you do to save on electricity consumption at school and at home? What concepts related to electricity do you know, and can you also explain their meaning?*

The teachers' questions and discussions, as well as the experiments from *The Electricity Book of Little John*, supported the children in thinking about electricity and how it affects their lives. Their thinking was further facilitated through *play and exploration*. The teachers organised playful explorations related to circuits and conductive materials, enabling the children to

develop their understanding in fun and child-centred ways. The materially mediated and embodied activities enabled the children to investigate an invisible phenomenon—electricity—through tangible means. For young children, the use of one's own hands and body is the first step towards learning and is a prerequisite for using imagination to understand abstract concepts.

Designing and making the Power Creatures were the most time-consuming phases of the project; altogether, these parts lasted for 10 lessons, that is, half of the project's lessons. Hands-on activities with young children require time because of their still developing fine-motoric skills but also because meaningful hands-on work requires time for reflection. Children need time and support to understand the meaning of their activities in a way that enables their engagement and learning. In the Power Creatures project, the teachers facilitated children's *problem solving and agency* with a carefully planned design and making task. The open-ended task required the children to formulate their own subproblems—that is, how to design the creature so that it would reflect the strengths and other character traits they wanted. The teachers guided the children to draw creatures that depicted where they find strength in their everyday lives. They also supported the children's design by discussing previous activities in the project. The task was clearly motivating for the children because they empathised with the power figures, talked about their qualities eagerly and wanted to present their ideas to adults and other children.

During the making phase, in small groups, the teachers discussed and demonstrated several stages of the manufacturing process. For example, they pondered together about what the meaning of the pattern is, and the teachers reminded the children how scissors are used. Safety issues were highlighted especially in the needle felting phase; the teachers instructed the children to keep their fingers away from the sharp needle. The teachers also invited school students and parents to work with the children for two reasons. First, the aim was to guarantee enough hands-on support for the children, and the second aim was to enable cross-age *dialogue and collaboration* while making. On the one hand, the older students and parents were more competent in tasks requiring fine-motoric skills, but on the other hand, the children were experts regarding their own designs. This ensured both equal collaboration between the younger and older participants and a smooth progression of the making phase. Overall, the implementation of the design and making phases enabled several focused 'flow' experiences for the young children.

Throughout the project, the teachers fostered the children's awareness of their own thinking and learning, encouraging their *reflection, reasoning and assessment* of the process. They regularly offered the children the possibilities to practice self- and peer-evaluation, helping them articulate their thoughts. Besides verbal expression, the teachers considered children's embodied activities and tangible products (i.e., circuits, drawings, finished creatures) as important realisations of their thinking and learning. At the end of the project, the initial idea was to use story crafting for the teachers to get a final grasp of the children's understanding of the phenomenon of electricity. Although this was not carried out as planned, overall, the project highlighted several aspects related to young students' learning through investigative activities.

Conclusions

The aim of the present study was to explore how pre-primary students' learning of everyday technologies can be supported with investigative activities—that is, activities combining inquiry-based and creative hands-on activities. The conceptual framework of the synergies between inquiry-based and creative approaches by Stylianidou et al. (2018) supported the analysis, focusing our attention on children's activities and the pedagogical practices that foster both inquiry and creative hands-on activities. The analysis revealed that the synergies were present in the project, suggesting that the two approaches can be combined in pre-primary technology education. Furthermore, the results indicate that hands-on work with craft materials and tools can be successfully implemented in the learning process. The longitudinal STEAM project provided a groundwork for mixing various activities in a pedagogically meaningful way. This is the core of Finnish pre-primary education: to create learning modules in which diverse fields of knowledge are integrated to improve children's transversal competencies (FNBE, 2016).

Learning about everyday technologies—in this case the basics of electricity—took place through several iterative cycles of inquiry-based and creative, hands-on activities. The use of technological tools was first practised during the completion of simple tasks, and the newly learned competences were then adapted for creative purposes (Kilbrink et al., 2014). The simple tasks supported, for example, learning the names and functions of circuit components, but it was the holistic process with its diverse activities that provided the basis for understanding the meaning of the phenomenon. Milne and Edwards (2013) reported that five-year-old children were able to transfer their understanding of a technological process from one situation to another when they had sufficient language skills and background experience to support it. The more diverse the experiences the children have with technology, the easier it will be for them to learn new skills. The initial technological exploration that is associated with the creative process quickly turns into a structured activity when repeating the same type of identifiable activities (Harwood & Compton, 2017; Mawson, 2010). In the present study, the children were able to build their knowledge related to everyday technologies through various embodied and material experiments. Their understanding became visible to themselves and others through the design and making of the Power Creatures.

The results of the present study indicate that investigative activities support children's capacity to explore and understand electricity in their everyday lives. Furthermore, the findings show that teacher scaffolding and involvement throughout a project is crucial for its success and for the development of children's understanding. However, because the present study explored the supporting pedagogical practices on a more general level, additional research on the various approaches to scaffolding investigative activities in pre-primary technology education is needed (Marsh, 2016).

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Spatial cognitive processes involved in electronic circuit interpretation and translation: their use as powerful pedagogical tools within an education scenario

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Abstract

While there is much research concerning the interpretation of diagrams such as geographical maps and networks for information systems, there is very little on the diagrams involved in electrical and electronic engineering. Such research is important not only because it supports arguments made for other types of diagrams but also because it informs on the cognitive processes going on while learning electrical and electronic engineering domains, which are generally considered difficult to teach and learn. Such insight is useful to have as a pedagogical tool for teachers. It might also benefit would be self-learners, entrepreneurs, and hobbyists in the field because it can guide self-learning practices. When cognitive practices specific to this knowledge domain are more understood, they might give rise to automated intelligent tutor systems which could be used to augment teaching and learning practices in the education of electrical and electronic engineering. This research analyses the spatial cognitive processes involved in the translation of an electronic circuit schematic diagram into an iconic representation of the same circuit. The work shows that the cognitive affordances of proximity and paths perceived from a circuit schematic diagram have great influence on the design of an iconic diagram, or assembly diagram, representing a topologically equivalent electronic circuit. Such cognitive affordances reflect and affect thought and can be used as powerful pedagogical tools within an educational scenario.

Keywords

Electronics engineering education, circuit schematic and assembly diagram, design and technology, cognitive processes, spatial thinking, visual analysis.

Introduction

Schematic diagrammatic representations in the field of electrical and electronic engineering have much in common with diagrams in information systems design in that they represent the abstract entity of electricity and its flow through components with specific behaviours. An electrical circuit schematic is defined by its structure, and the typical behaviour of the components within it. Overall structure and individual behaviours give rise to the function which the circuit is designed to accomplish (de Kleer, 1979, 1984; de Kleer & Brown, 1983). Electronic circuit schematics also represent the presence of real physical components and the connectivity networks between these components, often called a netlist. As such, they can be translated into other diagrammatic representations more suited for the physical assembly of an electronic circuit, or indeed directly onto a real assembly without the need for translation. In prototypic work on electronic circuits within an educational scenario it is typical to use physical

tools such as breadboards and copper stripboards to implement the circuits for testing. Experts or experienced electronics personnel can usually assemble an electronic circuit directly from a schematic diagram without the need for a mediating diagrammatic representation. Novice students in electronics engineering or non-experts, like assembly line workers, may need a mediating diagrammatic representation to aid the proper assembly of an electronic circuit since reading directly from a schematic diagram involves a significant amount of knowledge and also a significant cognitive load.

This research investigates the design behaviours of novice students in electronics engineering when asked to translate an electronic circuit schematic diagram into an iconic assembly diagram using specific software. The research does not exemplify how well the students understood the abstract circuit function, but only their design decisions when translating between representational diagrams. The aim of this work is to:

1. Investigate how novices interpret a circuit schematic diagram and relate this to the creation of a corresponding iconic diagram, which eventually would lead to a real functional circuit;
2. Discover error patterns which may occur when they translate between electronic schematic diagrams and electronic iconic diagrams. This could facilitate and hasten fault finding practices within an educational setting since both teachers and students would know what to look for when checking circuits; and
3. Inform pedagogical practices in the electrical and electronic engineering domains.

Accomplishment of these aims is targeted at the concern that the content of electronics topics is poorly represented in the learning process in general, not only within the area of design and technology and engineering, but also within other science subjects such as robotics, physics, and computer science (Rihtaršič, Stanislav, & Slavco, 2016). Recent research suggests that although electronics education could be considered as one of the key linkages within STEM/STEAM education, it is often neglected (Kocijancic, 2018).

The features of electrical and electronic schematic diagrams

Early depictions of electrical circuits emphasized the visual appearance of components. The diagrams had an iconic nature because the level of realism within the illustrations focused on the appearance of the objects within the circuit. By the year 1900, symbols were developed for electronic components and the nature of the diagrams shifted over to being more schematic in nature (Hegarty, Carpenter, & Just, 1996). The salient change of perspective from iconic diagrams to schematic diagrams is that the graphic symbols and organisation of these do not primarily represent the physical positions of objects, but the functional features of their electrical connectivity (Gregory, 1970). The conventions developed for schematic circuit diagrams indicate both the type of components and their connectivity network. Hence, schematic circuit diagrams are external representations which convey concepts that are inherently spatial as well as others which are metaphorically spatial. Although symbols play an extremely important role in the transfer of information through schematic circuit diagrams, they are not the only important elements in the process of recognising diagrams. A large number of unorganised circuit components as well as their mutual position in the whole circuit structure may significantly impede the transition of information via circuit diagrams (Pudlowski, 1988).

The primary focus of schematic electronic circuit diagrams is to depict both abstract concepts and physical realistic objects. An example of an electronic schematic diagram is shown in Figure 1. The circuit in Figure 1 is also that which will be analysed further for the scope of this research.

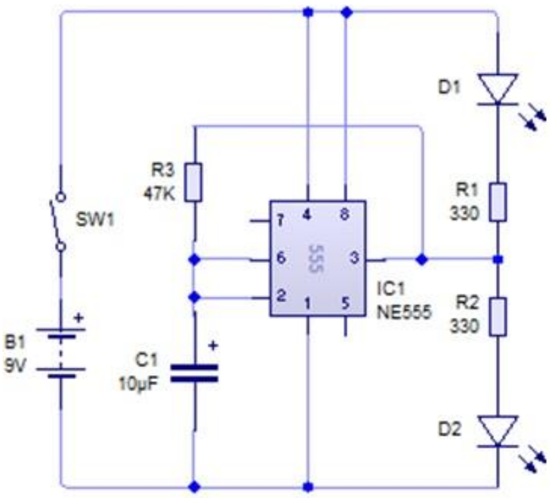

Figure 1: Schematic diagram of an electronic circuit having the function of a timer

Generating a topologically equivalent electronic circuit assembly diagram

The context of this research takes place within an educational scenario whose intent was to teach some practices within the domain of electronics engineering. One of the practices involves the translation of an electronic schematic diagram into a real prototype circuit. This can be done in a variety of methods, but for the scope of reaching the intended educational learning outcomes, it was required that the prototype circuit be implemented on a stripboard. A stripboard is a thin, rigid wafer with copper strips and holes on which the real circuit components may be soldered. The educational learning outcome required that the practical implementation of the prototype circuit is preceded by a software implementation that would enable the makers to plan, visualize and test the end product before making it. To this end, the software called Fritzing^{TM} (Knöring, Wettach, & Cohen, 2009; Wettach et al., 2007) was used. Fritzing is an electronic circuit prototype planner aid. With such software the maker can select electronic components from a parts bin, place them on the stripboard and connect them accordingly. When clicked, these iconic representations also reveal the corresponding symbolic schematic representations of the electronic components. Figure 2 gives a snapshot of how the iconic representation of a stripboard (Figure 2a) and the parts bin (Figure 2b) appear in Fritzing software.

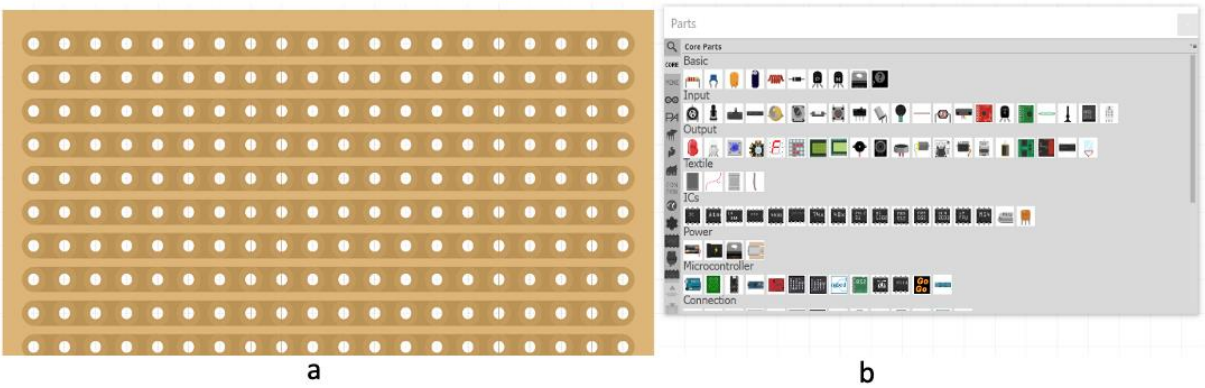

Figure 2. Fritzing™ interface showing copper stripboard and parts bin

Prior research on the representation of circuits through diagrams

In most past studies on electrical circuit diagrams, the representation of the electrical circuit was conveyed via a circuit schematic employing standard symbols or through a verbal description of the circuit. Studies such as that of Engelhardt and Beichner (2004) also employed realistic displays of circuits. A global view of all schematic circuit diagrams in most of the past studies gives the impression that, within any one of these, authors do not seem to employ a deliberately designed method of positioning the electrical symbols of the schematic with respect to a common framework, such as a vertical or horizontal organization of the circuit diagram. Although experts in the field of electronics normally do employ such a technique for drawing standard circuit diagrams, they might do so quite unconsciously drawing on experience rather than through conscious design (Marshall, 2008).

In electrical circuits, it is the topological connections that matter most and not the geometry of the schematic diagram. Nevertheless, even if this may only be a cognitive aid rather than a necessity, the way an electrical circuit is drawn may impinge on the cognitive load necessary to envision the function of the circuit (Amigues, Cazalet, & Gonet, 1987; Beeson, 1977; Caillot, 1985; de Kleer & Brown, 1983; Johsua & Dupin, 1985; Marshall, 2008; Pudlowski, 1988).

Cognitive processes involved in translating an electronics schematic diagram into its iconic counterpart

Highly specialized abstract content, like electrical circuit diagrams, impose challenging processing demands because the presence of higher order relationships in these scientific diagrams seems not to be readily apparent (Lowe, 1988, 1989a, 1989b, 1990, 1994, 1995). Novices in a field seem to benefit from diagrams whose significant attributes are made to *stand out* or *go together*, thus highlighting meaningful visuo-spatial relationships within the diagram and guiding attentional shifts by the very structure of the data (Egan & Schwartz, 1979; Grant & Spivey, 2003; Larkin & Simon, 1987; Lowe, 1994; Pule' & McCardle, 2010). Indeed, the management of the perceptual properties of a diagram was found to be key to generating insight in problem solving tasks and increasing significantly the frequency of correct solutions (Grant & Spivey, 2003). This may be achieved by controlling the relative dominance and perceptual precedence of a graphic object within a diagram. By manipulating attributes such as relative size, protuberance, minima of curvature, isolation, strength of boundaries and colour, the reader may be directed to shift his/her attention towards particular salient graphic objects

in a diagram earlier or later when the diagram is perused (Hoffman & Singh, 1997; Winn, 1991). Thus, the pre-attentive organization of information by means of what Winn defines as *configuration* and *discrimination*[1] has direct implications on cognition and learning, and the way in which perceptual groups are formed largely determines how the information in a diagram is encoded (Winn, 1991). Significant affordances which a page can offer include the attributes of proximity, position and paths. Proximity and use of space augments topological information with Euclidean space by categorizing subsystems in clearly defined perceptual groups. Position is normally divided into the horizontal and vertical directions, each metaphorically representing entities such as time, actual spatial position or abstract concepts. Paths are usually used to indicate real or metaphoric connectedness and relationships (Crilly, Blackwell, & Clarkson, 2006; Nickerson, Corter, Tversky, Zahner, & Rho, 2008). It is noteworthy to mention that, since these perceptual processes are pre-attentive and organize the data directly, they should not be affected by the reader's characteristic content knowledge.

One potential source of difficulty with interpreting a diagram-based representational format may lie in the perceptual cues offered by the representation (Kaplan & Simon, 1990). Perceptual features, such as structure, allow inferences to the function of a representation, and may form perceptual-functional units, or affordances. The perceiving of function typically entails observing or knowing about elements in action or interaction, what de Kleer and Brown (1983, p. 156) call *'envisioning'*. With experience, people can come to make functional inference from perceptual form and appearance (Tversky, 2005).

Physical and Cultural Experiences

When a diagram is used to represent abstract concepts, the metaphorical mappings of the diagram's structure are usually based on our physical and cultural experiences. These may have become so internalized that we grow unaware of them. The conditions for our experiences depend on constraints such as the three-dimensional space in which we live. Thus, for example, our immediate space is constrained by a local upright direction determined by the Earth's gravitational field and a flat, solid surface, orthogonal to the local upright direction, which bounds our immediate space from below. This gives rise to the spatial orientational metaphor such as the up-down dimension which is ubiquitous and salient in the structuring of our perceptions, cognitive maps or verbal descriptions. The upward direction dominates the downward direction since things above ground are more accessible (Blackwell, 1997; Boroditsky, 2000; Lakoff & Johnson, 1980; Shepard & Hurwitz, 1984). Another experiential constraint is the structure of the language we use to communicate. For example, the direction of writing horizontally from left to right in Western languages is usually used to express temporal sequence (Nickerson et al., 2008; Tversky, Kugelmass, & Winter, 1991). Considering these constraints together therefore, it is not surprising to note that we tend to read diagrams from left to right, top to bottom (Winn, 1991). Such mechanisms which were primarily developed for perceiving and reasoning about the spatial world are likely to be used for reasoning about other domains, for example electrical voltage potential, due to the interaction of representations in the mind and on the page. Due to their experiential basis, such metaphors prove to be very powerful when employed in search processes as applied to diagrams

[1] Configuration processes: objects or concepts which appear to form clusters, the sequences in which objects are processed and which objects later receive the most attention. Discrimination processes: how objects and processes are shown and the ease with which one object can be distinguished from another.

(Nickerson et al., 2008; Stenning & Oberlander, 1995; Winn, 1993). Humans are attuned to constraints in their physical environment and may benefit from a visual representation which limits abstraction (Blackwell, 1997; Kirsh, 2010; Stenning & Oberlander, 1995). By employing graphical constraining, the coupling between the elements in the visual display and the represented world becomes more tractable and supportive for the generation of inferences (Scaife & Rogers, 1996).

The Components of Device Knowledge

Kieras (1988) lists several kinds of knowledge people may have about devices, among which (a) the purpose for which it is used, (b) how to operate the device, (c) its inputs, outputs and connections, (d) its internal and external layout and appearance, (e) the functional relationship between its inputs and outputs, (f) procedures for maintenance and (g) its internal structure and mechanisms, that is, how it works.

These different kinds of knowledge about devices serve different purposes. Kieras (1988) argues that in the domain of electronic systems, knowledge which leads to inference strategies is usually not made explicit in training materials. It seems that the trainee is expected to pick these up by himself from examples in the training materials or during apprenticeship. This is not easy for a novice learner. The knowledge types (a) to (g) listed above lie on an increasing difficulty hierarchical scale, whereby inferring how a device works is exceedingly more difficult than, for example, understanding the purpose for which it is used, or how to operate it.

Most knowledge possessed by novices seems to be related to operating the device as opposed to explaining how it works. Even a task such as the maintenance of an electronics circuit may not involve knowing the design considerations behind the discrete component level, but only the identification of the malfunctioning components. For the purposes of this research, the type of device knowledge required was more of a procedural nature. Participants needed to know how to read and interpret the input and output connections of electronic devices, lay out the iconic appearance of the devices and ensure that the connectivity between them results in a functional circuit.

Circuit Schematic Diagram Representation and Interpretation – Chunking and Topological Influences

The work of Egan and Schwartz (1979) and Geiselman, Wickens, and Samet (1983) explores memory for symbolic electrical circuit diagrams and procedural knowledge respectively. The main outcome of this work is that skilled electrical technicians, that is experts in the field, recalled circuit diagrams by chunks of functional units, where symmetry in the diagram seemed to play an important role. This contrasted with novices who recalled the circuits on the basis of spatial proximity alone. This outcome has influenced the way circuit diagram was drawn in this research. The circuit was perceptually chunked to make it easier for participants to arrive at the salient functional units.

Intellectual Growth

Kosslyn (1980) states that during the imagery process a subject needs to first generate the image and inspect it, then consequently maintain it in memory and manipulate it. Mental representations are abstractions and by their very nature simplify and inevitably distort

information (Tversky, 2015). There are a multitude of possible mental transformations such as orientation, change of location, reconfiguration and rearrangements in length, width area, proportion etc. Many of such mental transformations appear to be internalizations of physical transformations. Things can be known only by the way humans have organized them perceptually and conceptually (Dusek, 2006; Guyer & Wood, 1998).

The topology of a system is typically embedded in the Euclidean plane and it is very difficult to avoid being influenced by the spatial features of a diagram. Visuospatial cues or their absence can have deleterious effects on people's interpretations of diagrams. This might lead to predictable biases and errors. Errors on isomorphic diagrams can probably be accurately predicted by deriving some salient spatial features of a model diagram (Corter, Nickerson, Rho, Tversky, & Zahner, 2009).

From an educational perspective, Bruner (1966, p. 5) states that '*intellectual growth is characterized by increasing independence of response from the immediate nature of the stimulus*'. Bruner claims that much of what the learner does is predictable from the knowledge of the stimuli that are impinging upon him at the time he responds or just prior to that time. A great deal of growth is present when the learner is able to maintain an invariant response in the face of changing states of the stimulating environment, or when he learns to alter his response in the presence of an unchanging stimulus environment. Bruner maintains that growth also depends upon internalizing events into a storage system that corresponds to the environment. It is this system that makes possible the learner's increasing ability to go beyond the information encountered on a single occasion. He does this by making predictions and extrapolations from his stored model of the world. Most importantly, intellectual development is marked by an increasing capacity to deal with several alternatives simultaneously, to tend to several sequences during the same period of time, and to allocate time and attention in a manner appropriate to these multiple demands.

According to Bruner, the structure of any domain of knowledge may be characterized in three ways: a) the mode of representation in which it is put, b) its economy and c) its effective power. Any idea, problem or body of knowledge can be presented in a form simple enough for any learner to understand it in a recognizable form. However, mode, economy and power vary in relation to different ages, to different styles among learners, and to different subject matters. Bruner maintains that any domain of knowledge can be represented in three ways:

1. By *enactive* representation. This type of representation is a set of actions appropriate for achieving a certain result. Bodies of knowledge can be known without having imagery or words to describe them. Such bodies of knowledge are very hard to teach to anybody by means of words or pictures and most often their transmission is based upon the learning of responses or forms of habituation.
2. By *iconic* representation. Iconic representation is primarily governed by principles of economical transformations in perceptual organizations. This type of representation is a set of visual or other sensory organization, usually dependent upon images or graphics which summarize and stand for a concept.
3. By *symbolic* representation. This type of representation is a set of symbolic or logical propositions drawn from a symbolic system that is governed by rules or laws for forming and transforming propositions. Symbols are arbitrary; there may be no analogy between

> the symbol and the object it represents. Symbolic systems provide the means of getting free of the immediate appearance of an object as the sole basis of judgement and usually, such as in the example of mathematical equations, offer the attribute of compactibility.

Actions, images and symbols vary in difficulty and utility for people of different ages, different backgrounds and different styles. Moreover, each of these can be context specific.

Besides the mode of representation, (Bruner, 1966) maintains that economy and power are also important features of the structure of knowledge representations. Economy in representing a domain of knowledge relates to the amount of information that must be held in mind and processed to achieve comprehension. The more items of information one must carry to understand or deal with a problem, and the more successive steps one must take to process information to achieve a conclusion, the less the economy. Economy varies with mode of representation and is also a function of the sequence in which material is presented or the way it is learned. Economy can be further increased by using diagrammatic notations. In addition, there may be varying degrees of economy within such recourse to the iconic mode of representation. Bruner gives an example featuring information about intercity flights, where the task is to determine the shortest distance from one city to another. He explains how different representations, in the form of: a) word list in random sequential order; b) word list in alphabetical order; c) a topological graph diagram with vertices standing for city names, and lines standing for the interconnection in between them; and d) a re-arranged topological graph diagram describe the information given. The economy and hence, effective power of utilization of each of these representations varied dramatically due to the way the information was presented. Bruner states that a structure may be economical and powerless, but it is rare for a powerful structuring technique in any field to be uneconomical. He relates this to the canon of parsimony shared by many scientists, that nature is simple, and only when nature can be made reasonably simple can it be understood. According to Bruner, the power of a representation can also be described as its capacity, in user terms, for connecting matters that, on the surface seem quite separate.

Bruner claims that apart from the mode of representation, and its economy and power, sequence of instruction is also key to effective learning. He states that the sequence in which a learner encounters materials within a domain of knowledge affects the difficulty he will have in achieving mastery. There is no unique sequence for all learners, and the optimum in any particular case will depend upon a variety of factors, including past learning, stage of development, nature of the material and individual differences. Bruner's key assertion about sequence is that if the usual course of intellectual development moves from enactive through iconic to symbolic representations of the world, it is likely that an optimum sequence will progress in the same direction. This is considered a conservative doctrine. For, when the learner has a well-developed symbolic system, it may be possible to circumvent the first two stages. The problem with this is that the learner may not possess the imagery to fall back on when his symbolic transformations fail to achieve during the act of problem solving.

Method

This research first involved the choice of a circuit function and the planning of a circuit schematic diagram suitable for the context of a design and technology or vocational

engineering technology class at secondary school level in Malta. This choice was based on the subject's curriculum for the award of a Level 3 qualification on the Malta Qualifications framework (MQF, 2010). To minimize bias within the generation and analysis of the data, two researchers worked independently and took two separate roles. One researcher was responsible for the planning and collection of data, while the other solely for its analysis. The second researcher was not involved in the selection of the circuit, the planning of its schematic representation or the administration of the exercise to participants. This ensured that the second researcher, who was an expert in electronics, was completely estranged as to what circuit configuration to expect and could not form preconceptions of how the circuit "should" look like from her personal mental imagery collection of electronic circuit schematics and assembly forms. It is well known that experts and novices in diverse domains such as physics, mathematics, computer programming and design organise, process and represent information differently from novices (Adelson, 1984; Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980; Novick, 1988; Schoenfeld & Herrmann, 1982). Research shows that experts perceive problems by means of deep abstract solution-oriented structures and categorize and index problems differently from novices. According to (Mervis, Johnson, & Scott, 1993) experts can notice and base their solutions on subtle perceptual attributes and their correlated functional affordances much more than novices. Indeed, they claim that expert performance is rooted in perception and that perceptual features may be integral to expert solutions. The lack of participation of the expert in the planning and data collection made sure that her influence on the other researcher and on the novice students would be null.

The participants were taken from a class following the subject of vocational engineering technology in a local Maltese secondary school. The class was a mixed gender, mixed ethnicity (majority European, minority Asian and African), classroom with ages ranging between fifteen and sixteen. The number of participants was eighteen (n=18) students. This sample was a convenience sample since the collection of data needed to coincide with the point in time when project work on electronic circuit assembly was being conducted by the class teacher as part of the normal curriculum. The participants were simply defined by that particular class who happened to be in the phase of circuit assembly during the time window available for the researchers to obtain access and collect data. Since the task was part of a normal lesson where schoolwork and homework was assigned and expected from students, the participants were not offered any rewards. The sample cannot be considered as representative of a wider population unless the research is repeated. The participants were given the circuit schematic diagram shown in Figure 1 and asked to translate it into a stripboard layout using the software Fritzing^{TM}. Such an exercise constituted part of the normal curricular work and was not accompanied by any textual explanations of the circuit. Participants presented their work as digital images showing a populated iconic circuit representation similar to Figure 7.

The analysis of the data was mainly qualitative and performed by taking a grounded theory approach since concepts were seen to emerge from the data by induction. The first step involved the scrutiny of the circuit schematic form and the extraction of its own features in an absolute way by an expert in electronics. Such features, if present, were hypothesized to influence participants' iconic designs. Consequently, the expert could form an initial personal hypothesis of how the novice participants could have potentially organised their circuit assembly.

The second step was to analyse participants' iconic diagrams to qualitatively search for any patterns. The analysis of the iconic diagrams commenced by human observation and comparison of the Fritzing software diagrams to the schematic circuit diagram which they were given to translate. The observations primarily searched the data for the retention of the topological equivalence of schematic and iconic circuit representations, however, the repeated instances of proximity, order and perceptual chunking were soon very readily evident while going through the data. These were the concepts arrived at by the process of induction and which could possibly be applicable to domains other than electronics and thus generalisable within a broader spectrum of design, technology and engineering education.

Results and Analysis

Analysis of the circuit schematic diagram in Figure 1 – results presented by the expert

The manipulation of visual images may reduce the load on working memory and speed up the process of inference (Scaife & Rogers, 1996). Human abilities to recognize information are highly sensitive to the exact form in which the information is presented to the senses and rearranging the elements of a particular representation may cause it to correspond to a different possible world (Larkin & Simon, 1987; Pudlowski, 1988; Stenning & Oberlander, 1995). If a circuit schematic is displayed to students and structured in a way that its components are arranged freely, it may lead to misinterpretation of the circuit's meaning and consequently confusion regarding its important functions. One aspect to consider when drawing circuit schematics is the mutual proportion of elements composing the entire figure. Appropriate proportions in terms of measurements and distribution of elements and lengths and angles between them may have a decisive meaning in the process of perception. When drawing a circuit schematic, it was found ideal to have a certain proportional relationship between the elements resulting in a degree of geometrical harmony (Pudlowski, 1988). The circuit in question was analysed for its conceptual affordances of paths, proximity and position (Nickerson et al., 2013).

The circuit in Figure 1 is an astable multivibrator with two functional sub-circuit chunks. The first, referred to as the LED path, is the closed loop path which includes the 9 V battery; the single pole single throw switch, SW1; the upper LED, D1; the resistor R1; the resistor R2 and the lower LED D2 which returns to the negative terminal of the battery. Figure 3 shows this as a path affording enclosure. The block diagram of the same path in Figure 4 shows that this path has one bifurcation at the connection between resistor R1 and R2 leading on to pin 3 of the integrated circuit (i.c.).

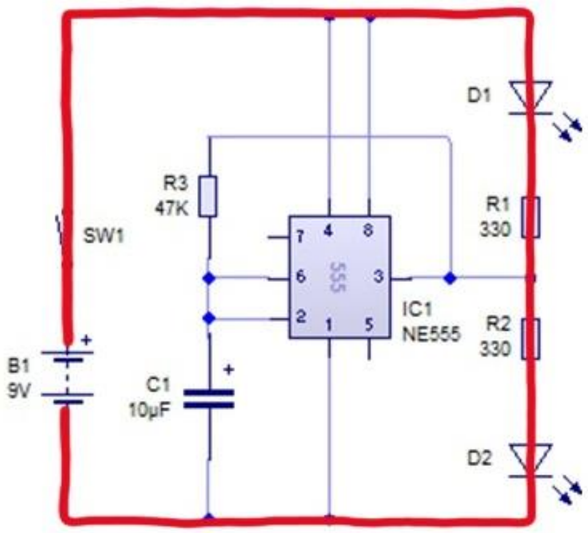

Figure 3: LED path on schematic diagram

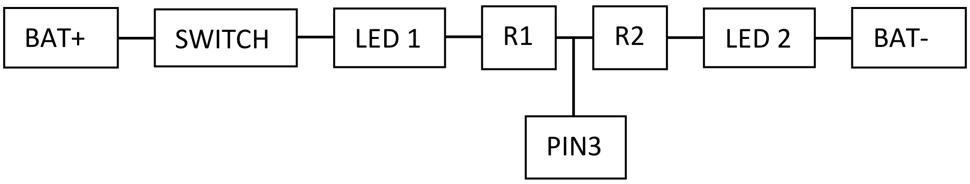

Figure 4: LED path as a block diagram

The other functional sub-circuit chunk is part of the charging-discharging path, referred to as the RC path: from pin 3 of the integrated circuit to resistor R3 to capacitor C1 and to the negative terminal of the battery which can be considered to be the ground point of the circuit. This is shown in Figure 5, where clearly, there is no enclosure afforded. Its corresponding block diagram, Figure 6, shows that in between resistor R3 and capacitor C1, there are two bifurcations leading to pin 2 and pin 6 of the integrated circuit.

The perceptual nature of these paths already suggests that the RC path might offer greater cognitive challenges than the LED path.

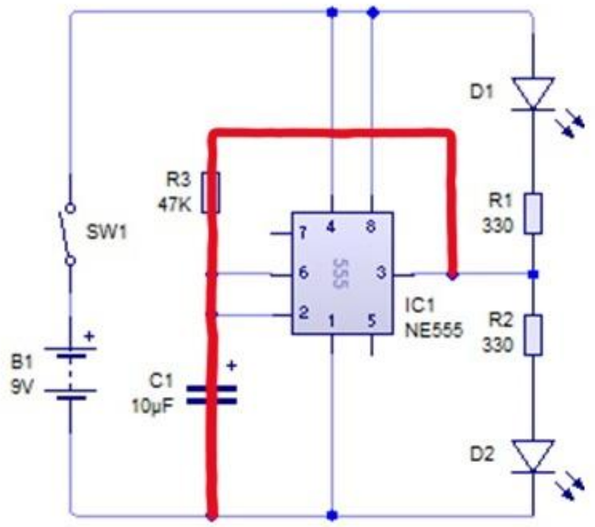

Figure 5: The RC charging-discharging path

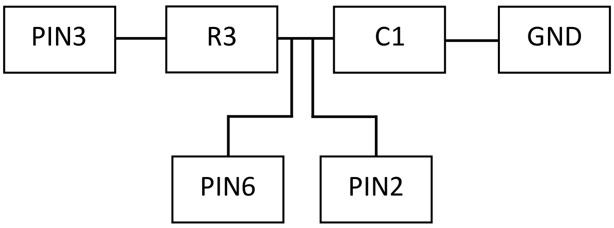

Figure 6: The RC path as a block diagram

Results and Analysis emanating from participants' iconic circuit representations

Results and analysis for the iconic representations of Figure 1

The analysis of the iconic representations was divided into two sections. The first section focused on the positioning of key components or related sub-chunks with respect to a Euclidean grid and with respect to each other. The second section of the analysis focused on the continuity of the paths within the two main functional sub-circuit paths: a) the LED path and b) the resistor-capacitor (RC) path. Figure 7 shows one sample of the populated iconic representations which were analysed. Fritzing software retains the physical dimensions of all iconic instances as constant, hence automatically ensuring that the scale of the iconic representations is identical. Length measurements taken on the iconic representations were therefore taken with respect to a common scale.

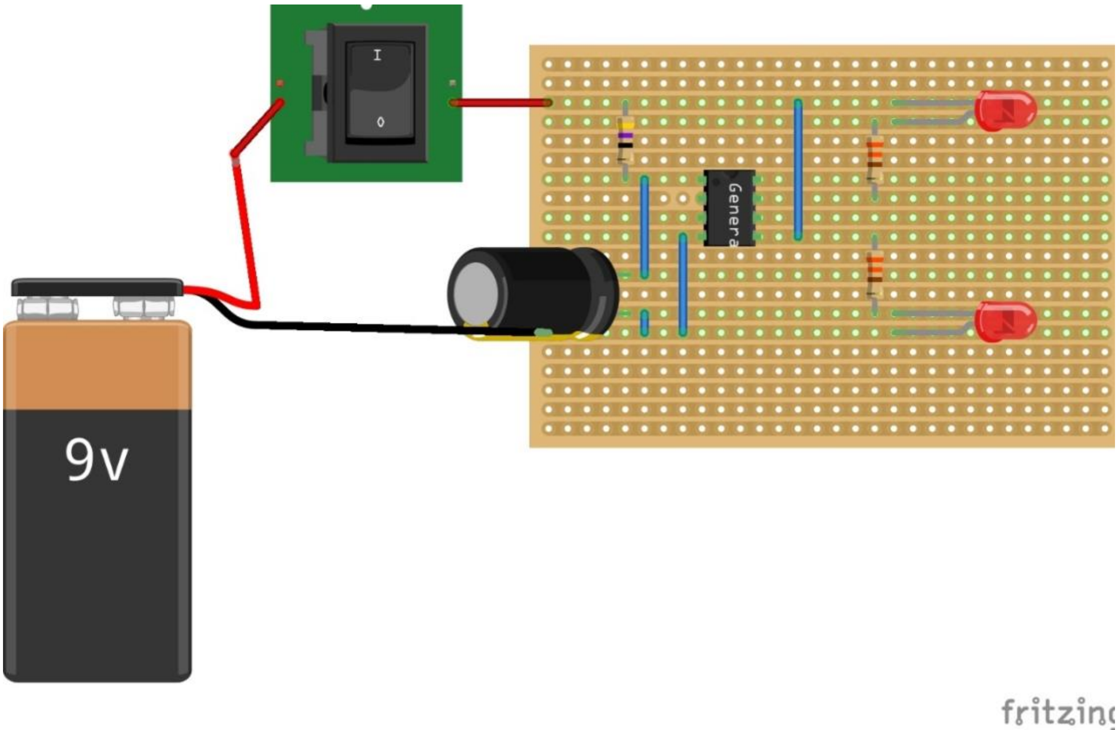

Figure 7: One sample of the populated iconic circuit representations on Fritzing gathered from participants

Section 1: Symbolic to Iconic representations

The electronic circuit schematic diagram was read correctly by all participants. All circuits presented in stripboard layout had the correct number of components on the board. All stripboard layouts also had the correct iconic representations corresponding to the circuit schematic symbols. Slight variety was only noticed as regards to the type of switch chosen (push button or toggle) and the type of capacitor chosen (ceramic type or electrolytic type). Both these choices had no significant effect on the functionality of the circuit. There were no instances of misinterpreted circuit schematic symbols.

Section 2: Stripboard Layout Proximity and Position of sub-circuit chunks

The proximity of the circuit symbols within the schematic diagram was measured by circumscribing the relevant path symbols with a circle and recording its diameter as shown in Figure 8. The ratio of the respective diameters on the circuit schematic given to participants was calculated as follows:

$$\frac{proximity\ of\ LEDs\ in\ schematic\ diagram}{proximity\ of\ RC\ in\ schematic\ diagram} = \frac{diameter\ of\ P_{LED}}{diameter\ of\ P_{RC}} = 1.6723$$

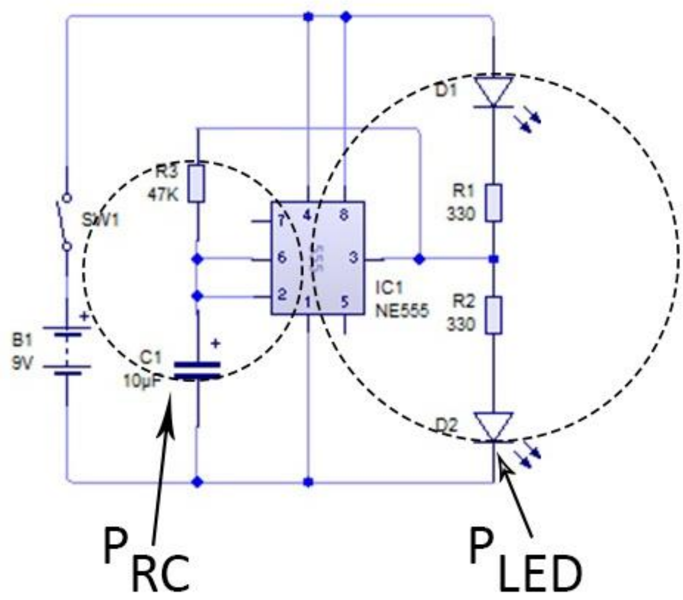

Figure 8: Measuring the proximity of components within the two main sub-chunks of the circuit schematic

The same was done for all stripboard layouts designed by the participants. The two main sub-chunks of the circuit on the stripboard layout of all participants were circumscribed by two circles and the ratio of the diameters was calculated. From the measurements on the stripboard layouts the average proximity of the paths is:

$$\frac{proximity\ of\ LEDs\ on\ stripboard\ layout}{proximity\ of\ RC\ on\ stripboard\ layout} = 1.6510$$

It is striking that the average ratio of proximity of components on the stripboard layout is so close to the ratio of proximity of components on the schematic diagram. It seems that participants perceived cognitive spatial measurements on the schematic diagram were transferred onto the stripboard layout design even if this was not required and did not affect the functionality of the circuit in any way. It seems that participants preferred to retain the spatial distances between circuit symbols and circuit iconic representations.

Such proximity indicates that the sub-chunks were readily recognized. It also acts to support research such as that of Egan and Schwartz (1979) who discovered that novices tend to chunk circuits according to a proximity criterion. Indeed, this phenomenon also resonates with the findings of (Piaget & Inhelder, 1956, 1971) whose research is more scientifically generalizable since it is about human development in general. In their work on the child's conception of space, Piaget and Inhelder suggest that within the first stages of development, proximity is more important than other factors of organisation, such as resemblance or symmetry. The findings that link so closely the proximity factor on the circuit schematic to the proximity factor on the iconic representations infer that participants are still in the initial phases of development of the knowledge domain in electronics education, which is indeed the case.

Section 3: Stripboard Layout Position, Order and Proximity of key components

This section focused on the positioning and order of key components or related sub-chunks with respect to a Euclidean grid and with respect to each other. By the first round of observation of the data, the researcher was able to extract patterns which were evident for the salient components of the circuit. These macro features were verbalised in qualitative statements which could be classified by the Boolean descriptors: “true” or “false”. The statements were classified for every iconic circuit representation collected from the participants. Consequently, the percentage of participants for which the respective statements were true was calculated from the summation of the responses.

Table 1: Method of coding the iconic diagrams for the layout and order of salient components

	Statement	True	False
1	The battery is positioned to the left of the stripboard.	□	□
2	The battery terminals are upwards (north facing).	□	□
3	The i.c. notch is upwards.	□	□
4	The strips of the stripboards are horizontal.	□	□
5	Both resistor and capacitor (RC path) are to the left of the i.c.	□	□
6	The resistor (RC path) is above the capacitor (not necessarily vertically aligned).	□	□
7	The resistor (RC path) is vertically aligned to the capacitor.	□	□
8	The LEDs are positioned to the right of the i.c.	□	□
9	The LEDs are vertically aligned to each other.	□	□

The battery

The majority (94.4%) of participants positioned the iconic image of the battery on the left side of the stripboard. The battery was positioned vertically with its terminals pointing upwards in 66.67% of the cases. Most participants who rotated the battery on its side positioned the positive terminal above the negative terminal.

The NE555 integrated chip

The position of the integrated chip was always central with respect to other components of the circuit. Indeed, the i.c. seemed to be regarded as the visual centre of mass of the circuit. Most participants (94.4%) positioned the i.c. with its notch in the upward position when the strips of the stripboard were horizontally aligned. Aligning the copper strips horizontally has a practical advantage and participants may have been purposefully instructed to always align the i.c. as such with respect to the copper strips. The advantage of this orientation lies in the fact that, in this position, fewer isolation cuts are necessary to prevent some of the i.c. pins from being shorted by the copper on the stripboard. Participants may have been alerted to this by their teacher and therefore the high rate of compliancy is probably biased by prior teaching interventions. This can be considered as a source of constraint (Kaplan & Simon, 1990).

The resistor-capacitor charging-discharging sub-chunk path

In 77.78% of the cases, participants positioned the 47kΩ resistor, R3, and the 10µF capacitor, C1, to the left of the NE555 integrated chip. In 72.22% of the cases, the resistor was positioned above the capacitor, while in 33.33% of participants aligned R3 vertically with respect to C1.

The LED sub-chunk path
The LEDs, D1 and D2, together with their respective series resistors R1 and R2, were positioned to the right of the NE555 integrated chip for 72.22% of the cases. Most participants (63.89%) aligned these components vertically to one another.

In their research (Kotovsky & Fallside, 1989) discovered that subjects tend to always adopt a suggested representation instead of choosing deliberately between different ones. According to (Tversky, 2015) there is various kinds of evidence which suggests that the mind attempts to align different experiences and modalities by selecting shared elements, identifying a frame for the elements and aligning the reference frames and elements. This entails cognitive sub-processes such as finding the critical elements, determining the appropriate reference frame and then aligning them.

Participants chose to imitate closely the schematic layout of the circuit when designing the iconic stripboard layout. This is typical of novice learners (Pudlowski, 1988, 1993). The layout is not just an imitation of the schematic but also conforms to the perceptual preferences which were discussed beforehand. Both schematic and iconic circuits conform to the dominant configuration of having the upper areas representing the 'dominant' positive power rail. Both schematic and iconic circuits conform to a left to right reading structure, which also happens to coincide with the implicit knowledge within the domain of electronics, of drawing inputs and source components on the left, the process components in the middle and the output components on the right as shown in the general system block diagram of Figure 9.

Figure 9. Implicit way of drawing systems

It is therefore clear that the spatial order, sequencing and even proximity of the symbols in the schematic diagram has greatly influenced the design of the iconic stripboard diagram. This is in support of the arguments emanating from the literature.

Section 4: Path analysis
This section of the analysis focused on the continuity of the paths within the three main functional sub-circuit paths: a) the LED path and b) the resistor capacitor (RC) path and c) the power rails. Qualitative statements describing the netlists of all paths were listed as in Table 2. The researcher classified the statements for each iconic representation presented by the participants.

Table 2: Statements describing netlist of the timer circuit of Figure 1

	Statement: The following path is connected correctly:	True	False
1	Pin 8 to supply (direct or after switch)	□	□
2	Pin 4 to supply (direct or after switch)	□	□
3	Pin 1 to ground	□	□
4	Pin 3 to resistor RC, to R3	□	□
5	Resistor RC (R3) to C	□	□
6	Capacitor to ground	□	□
7	Pin 6 to mid RC	□	□
8	Pin2 to mid RC	□	□
9	Battery positive to switch	□	□
10	Switch to LED D1	□	□
11	LED D1 to R1	□	□
12	R1 to R2	□	□
13	Pin 3 to mid R1 and R2	□	□
14	R2 to LED D2	□	□
15	LED D2 to ground or negative of battery	□	□

Connection of the i.c. to the power rails

The circuit required pin 8 and pin 4 of the integrated circuit to be connected to the positive terminal of the power supply, and pin 1 to the negative terminal of the power supply as shown in Figure 10. The results show that 77.78% of the participants connected pin 8 correctly to the positive rail, 61.11% connected pin 4 correctly to the positive rail, but only 50% connected pin 1 correctly to the negative rail. Taken collectively, the percentage of students who connected the power rails correctly was 62.96%.

It is of interest to note that there were instances where pin 1 was erroneously connected to the positive rail, while pin 4 was connected erroneously to the negative rail. Figure 11 shows the pins and their corresponding pin numbers of the iconic integrated circuit on the stripboard. Clearly pin 1 and pin 8 are symmetrical about the vertical plane, while pin 1 and pin 4 are symmetrical about the horizontal plane. When the pins were connected incorrectly, it seems that in such instances, the mind's valency for horizontal left-right symmetry (pin 1 with pin 8) or vertical directional asymmetry (Casasanto & Henetz, 2012) might have been the cause for the erroneous connections. The participants' reaction may be the result of the co-operation or competition between the two important features: one geometric and the other semantic (Van Sommers, 1984). In this case it seems that the geometric feature dominated the semantic feature resulting in an erroneous connection.

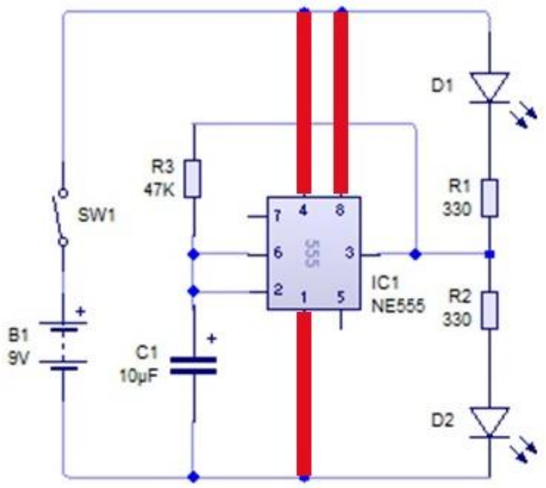

Figure 10: Power rails within the circuit schematic diagram

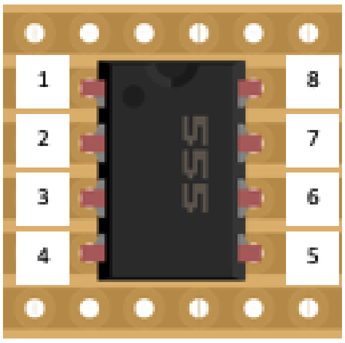

Figure 11: Iconic representation of the NE555 timer integrated circuit

Connections for the LED path

Table 3 shows the percentages of correct connections for each path in the netlist of the LED path. Considering that this path exhibits vertical symmetry about the point where resistor R1 meets resistor R2, connectivity errors for the upper half of the circuit were less than those for the lower half of the circuit. This seems to suggest that students were less confused when connecting the upper half of the path in question. When taken collectively, the percentage of students who connected the LED path correctly is 80.95%.

Table 3: Continuity breakdown of LED path

Connection	Percentage of participants who connected the given paths correctly (n=18)
Battery positive to switch	83.33%
Switch to LED named D1	94.44%
LED named D1 to resistor R1	88.89%
Resistor R1 to resistor R2	77.78%
Resistor R2 to LED named D2	50.00%
LED named D2 to negative terminal of battery or ground point.	77.78%

Connections for the RC path
Table 4 shows the percentages of correct connections for each path in the netlist of the RC path. The two paths with the least amount of connectivity errors are a) the path from resistor R3 to capacitor C1 and b) the path from capacitor C1 to ground. These paths are visually evident as vertical paths in the circuit schematic. The other three netlist paths within the RC path are seen to visually branch out at 90 degrees from the main vertical stem. This vertical stem can be considered as the “line of action”, (Hegarty et al., 1996, p. 664), connecting the resistor to the capacitor. All three branching sub-paths which do not lie within the line of action exhibit a greater amount of connectivity errors from participants. Taken collectively, the percentage of students who connected the RC path correctly is 53.33%.

Table 4: Continuity breakdown of the RC path

Connection	**Percentage of participants who connected the given paths correctly (n=18)**
Pin 3 to resistor R3	50.00%
Resistor R3 to capacitor C1	55.56%
Capacitor C1 to negative terminal of battery or ground point.	77.78%
Pin 6 to mid-point of R3-C1	38.89%
Pin 2 to mid-point of R3-C1	44.44%

It is possible that participants have used a prior learnt structure, such as a sequential chain, to understand concepts and make inferences for circuits in electrical and electronics engineering. This would be rather natural since electricity always flows in closed loops and this is what is taught in any physics or engineering class. Research about concepts in electricity highlight common dominant misconceptions brought about by sequential reasoning and sequential biases (Duit, Jung, & von Rhoneck, 1984; Taylor & Tversky, 1992). It is therefore not surprising that the path which was connected most correctly was the LED path (80.95%), rather than the power rails (62.96%) or the RC path (53.33%). The LED path is the only path out of the three that perceptually affords a closed loop structure and that has components which can be seen to be positioned in a spatial clockwise succession, offering enclosure of the other components. Out of all three paths, the LED path is the one that appeals most to primitive cognitive processes which are probably deeply rooted into the participants’ cognitive abilities. The power rails afford a degree of symmetry about the horizontal plane and seems to have afforded medium difficulty of interpretation. The RC path is cognitively the most taxing since its flow involves a reverse reading order from right to left. Clearly, the novice participants still need to develop cognitive spatial skills to read, interpret and act, or possess “spraction” (Tversky, 2015), for those paths needing a greater cognitive load.

Limitations
The number of participants approached for this research is small and they were appointed only by convenience because that was permitted by ethical regulations governing the scope of this project. As such, the repeatability of the work cannot be claimed yet. The process of analysis for this research relied only on one human researcher who was experienced in electronics education and in teaching and the only one who accepted to act as analytic researcher. The

analysis could benefit either by having more than one person analysing the data or else having the analysis automated through the use of image processing techniques and machine coding as in the work by Nickerson et al. (2013). This would make the analysis more objective and much more accurate and rich quantitative measurements and relations would be possible.

Discussion

This work has shown that the spatial features of a circuit schematic diagram have considerable influence on novices' performance on a would-be procedural task and are considered to be "powerful", by Bruner's definition. The stripboard was essentially a blank area which could have been populated in any way, if the electrical topological connections were retained as those for the schematic diagram. The electronic circuit function would still have been achieved with an iconic circuit assembly diagram that had nothing in common with the schematic diagram other than the topological relations. Indeed, when experts plan the assembly of a real circuit, there are usually other variables which need to be taken into account such as ease of maintenance procedures, access to salient connections for measurement purposes, heat dissipation, economy of space due to cost of production etc. The design variables which should govern the planning of an electronic circuit assembly diagram go beyond the topological connections present within the schematic. It is clear that the novices who participated in this research were not yet taking into consideration such higher order variables in electronic circuit assembly practices but were fixated into the lower level cognitive processes related to the connectivity of the circuit. The novices who participated in this research have yet to develop their intellectual growth of the domain.

It is also evident that careful design and awareness of the spatial features of a circuit schematic diagram could significantly aid pedagogical practices in the domain of electrical and electronics engineering. Different diagrams serve different roles and novices in a knowledge domain should be made aware of which design variables are best served by a diagram in question. An electronic circuit schematic diagram serves the role of representing the structure, behaviour and function of the circuit, but does not infer information about its physical attributes and possible causes of malfunction due to poor choices within the layout of the physical components. Thus, a circuit schematic diagram supports conceptual knowledge while a circuit assembly diagram supports procedural knowledge. The usual pedagogical sequence of presenting electronic circuits representations in a typical engineering class starts from the symbolic and goes to the iconic. This sequence is in reverse of what Bruner recommends and might explain the learners' difficulty encountered when translating between diagrammatic representations. Further research would be needed to determine an optimised pedagogical strategy to minimise such difficulties, however it would seem to be reasonable to conclude that the visuo-spatial design of an electronic circuit schematic diagram has considerable influence on novice learners. Powerful and economical design strategies that target proximity, paths and placement of electronic symbols together with evident chunking and easily perceptible lines of action can be powerful pedagogical tools to adopt within an electronic engineering class.

Although the main topic of this work focused on the assembly of one particular simple and common circuit, the outcomes of this study may prove useful for other technological domains at other levels of teaching and learning. In studies such as the ETL project with undergraduate engineering students (Entwistle, 2005; Entwistle, et al., 2005; Entwistle, Nisbet, & Bromage, 2005), it was noted that students were less likely to adopt a deep approach to learning during

analogue electronics work than in other topics because the analysis of analogue circuits recurrently proved difficult for a substantial proportion of students. The key points identified as essential for supporting understanding were (a) interpreting circuit diagrams, (b) imagining circuit behaviour, and (c) using simplifying transforms. Using powerful and economical design strategies which target the "perceptual form" of the circuit schematic, could prove useful for adopting deep approaches to knowledge in analogue electronics at a higher level than presented in this study.

The suggestion for necessitating a deeper approach to knowledge naturally instigates enquiry into what processes may be involved in understanding that knowledge and being able to provide a scientific explanation when communicating it. Kolari and Savander-Ranne (2004) state that in understanding, the nature of knowledge and the pattern of associations between its elements is most important. Merely measuring the amount of knowledge is insufficient when seeking to estimate understanding. Indeed Johnson-Laird suggests that a measure of understanding a phenomenon involves knowing:

> *what causes it, what results from it, how to influence, control, instantiate or prevent it, how it relates to other states of affairs or how it resembles them, how to predict its onset and course, and what its internal or underlying structure is (Johnson-Laird, 1983, p. 2)*

The outcomes of this work suggest that chunking and easily perceptible lines of action within a circuit schematic diagram could help in identifying the sub-systems within a circuit and therefore could aid in the adoption of a systems approach to understanding how the circuit works. In the astable circuit of Figure 1 learners should be able to relate the flashing frequency of the LEDs to the resistor-capacitor sub-system chunk and its related time constant. The understanding of relation of knowledge could start at the perceptual form, go through the systems approach and end within the more general scientific concept of how, in physics terms, time is related to frequency, and which components are responsible for the control of frequency in this circuit, thus satisfying Johnson-Laird's measure of understanding. According to Ausubel (1975) modifications to cognitive structure can be accomplished through manipulations of pedagogical content and sequence which could lead to conceptual changes into the cognitive structures of the mind (Langley & Simon, 1981; Rumelhart & Norman, 1981; Thagard, 1990; Vosniadou, 1994). This could potentially be true to domains other than electronic engineering.

Accessing cognitive structures of learners in a visual way is especially relevant to most topics in design and technology and engineering since the proportion of visual learners is typically high (Felder, 1988). The organisation of perceptual form might not just be an aid for deeper understanding of knowledge but also be a way of communicating it better through scientific explanations rather than descriptions. Explanations can be defined as scientific if, apart from providing a feeling of understanding, they provide a theoretical framework for a given phenomenon, while integrating a range of related phenomena and thus going beyond the initial, original phenomenal impetus (Brewer, Chinn, & Samarapungavan, 1998). As discussed previously, the outcomes of this work show that it is most probable that the organisation of perceptual forms in a diagram might influence deep understanding of knowledge and consequently this would be reflected in how the learner communicates that knowledge. The

methodology used in this work was largely dependent on visual analysis rather than verbal analysis of students' work due to the nature of the topic. It is conjectured that such visual analytic processes might be applicable for a range of other technological areas and contexts, especially those where the knowledge is visual or non-verbal. Such analytic methods might give precious insight into how visual and active learners (Felder, 1988) interpret knowledge and how to design research strategies and pedagogical practices for effective and efficient teaching of such learners.

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Meeting the Challenges of STEM education in K-12 Education through Design Thinking

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Abstract

This paper explores the ways in which the design thinking (DT) approach can be utilized in addressing the challenges of STEM education in K-12 education. The study is based on an extensive literature review about STEM education and the DT approach, and exploratory research conducted to understand the challenges and needs of STEM education in Turkey. The findings from the exploratory research indicate that STEM education in Turkey has significant challenges: The teachers have difficulties in integrating diverse disciplines and technologies into their STEM activities; the training programs for teachers and the general education for students encourage a result-oriented mindset rather than a process-oriented approach; and the teachers have difficulties in following the problem-solving process based on the engineering design approach. Furthermore, collaboration among teachers for developing and implementing STEM activities needs to be addressed as an important issue in terms of scheduling. Additionally, there is a need to develop STEM activities appropriate to the educational level of students. Equipping teachers with skills and knowledge appropriate to their new roles as guides and mentors should also be considered as a significant issue concerning the implementation of STEM activities. The study concludes that the DT approach as an interdisciplinary, collaborative, and human-centered problem-solving process can support STEM education and resolve the stated challenges. This study also suggests that there is a need to develop a customized DT approach for teachers, non-designers, so that they can easily apply their expertise to STEM education.

Keywords

STEM education, design thinking, design thinking for educators, design thinking in education, design thinking in STEM education in Turkey, design thinking in K-12 education

Introduction

STEM education aims to integrate Science, Technology, Engineering, and Mathematics disciplines, and has become widespread in Turkey in the last decade. However, the local and international works of literature show a tendency towards including a wide range of disciplines in STEM education (Ministry of National Education, 2016; Carrell, Keaty & Wong, 2020). There is also a need to design and implement the STEM activities appropriate to the educational level of students (Bruce-Davis et al., 2014; Uştu, 2019). Both works of literature further highlight the need for collaboration among teachers for the implementation of STEM education (Margot & Kettler, 2019; Akgündüz et al., 2015).

Design thinking (DT) is defined as a method to identify and solve problems in a human-centered way, and it has been applied in K-12 education to address a variety of challenges (Tran, 2017). This paper explores how the DT approach can be utilized to support STEM education and resolve the challenges it presents. With this purpose, the study is based on a literature review about STEM education and the DT approach, and exploratory research that reveals the

challenges and needs of STEM education in Turkey. This paper concludes by suggesting ways on how the DT approach can be used in STEM education.

STEM education

The acronym "STEM" stands for the first letters of science (S), technology (T), engineering (E), and mathematics (M), and in the literature, there are multiple definitions or perspectives on STEM education. However, common characteristics of STEM education can be found around the following: engaging students in real-world problem-solving, employing student-centered pedagogies, connecting STEM disciplines, and supporting the development of students' 21st-century skills (Moore et al., 2014).

Although STEM may be perceived as a simple acronym, many variants of STEM approaches that tend to integrate non-STEM disciplines into STEM education have been discovered in both works of literature. For example, in international literature, some scholars bring STEM together with humanities as HDSTEM (Carrell et al., 2020), in Turkey, some scholars emphasize visual arts by integrating 'A' into STEM as STEAM (Okka, 2019). Moreover, the National Science Foundation (NSF, 2015) defines STEM fields broadly, including not only common STEM fields, but also psychology, social sciences, economics, and sociology. In both works of literature, the place of a wide range of disciplines including humanities or arts education in STEM education is also questioned (Carrell et al., 2020; Daugherty, 2013; Ministry of National Education, 2016). This situation raises new questions about which disciplines STEM education includes and how non-STEM disciplines can be integrated into STEM education.

Currently, there is no extended national curriculum for STEM education in Turkey. Only changes have been executed in the national curriculum of primary and secondary school science education and technology and design education for the implementation of STEM education (Turkish Science Education Curriculum, 2018; Turkish Technology and Design Education Curriculum, 2018). According to this, the technology and design education curriculum focuses on the design-based product development process, based on creativity, innovation, and user-centered design. In the adoption of STEM education in Turkey, the technology and design teachers are further proposed to be trained for being mentors to other teachers (Ministry of National Education, 2016). In the science education curriculum, students are expected to develop solutions for daily life problems related to the subject within the scope of Engineering and Entrepreneurship Practices in every unit.

There are inequalities in the education system in Turkey. For example, socio-economically disadvantaged students go to schools that are considered low in performance and quality. When the competencies of 8th-grade students in mathematics are analyzed regionally, the rate of students who are below the basic competency level is quite high throughout the country; particularly in the eastern part of Turkey (Oral & Mcgivney, 2014). In connection with these problems, Uştu (2019) emphasizes the importance of preparing STEM activities which take into account the academic and social levels and the school contexts of students as well as the specific region in Turkey where the students are located. Furthermore, in the international literature, it has been discovered that teachers modify the existing STEM units or design new ones for the level of knowledge and skills of students (Bruce-Davis et al., 2014). Considering both works of literature, there is a need to design and implement the STEM activities appropriate to the educational level of students.

Although both works of literature highlight the need for interdisciplinary collaboration with teachers in STEM education, teachers need to allocate extra time to collaborate and prepare the materials (Margot & Kettler, 2019; Akgündüz et al., 2015; Okka, 2019). Moreover, the use of technology in STEM education is stated to be vague in international literature. Ellis et. al. (2020) point out the significance of matching the technology selection with the desired learning outcomes and considering how these are used within the context of the educational purpose. In the light of these points, analyzing students' skills, interests, and learning styles is important to choose the appropriate technology for STEM education.

Design thinking approach

The design thinking (DT) approach is not a new concept for designers and can be traced back to Herbert Simon's seminal work "The Sciences of the Artificial" which was first published in 1969 (Hassi & Laakso 2011). The DT approach has gained popularity through the efforts of the Institute of Design at Stanford (d.school), and American design firm IDEO, and particularly after Tim Brown, one of the IDEO's chairs and designers, wrote "Design thinking" in the Harvard Business Review (Brown, 2008; Tran, 2017). Currently, DT is applied in multiple contexts including education, management, engineering as an interdisciplinary, collaborative, and human-centered problem-solving process. The common purpose of applying the DT approach is to foster people's creative thinking skills and develop innovative, creative solutions to the problems by investigating the user's/stakeholder's needs (Leifer & Steinert, 2014; Lor, 2017; Chon & Sim, 2019).

Recently, DT has been applied in K-12 education, and one of the most important reasons for the use of the DT approach in the field of education is its human-centered principles and their applicability in the field of education (Diefenthaler, Moorhead, Speicher, Bear & Cerminaro, 2017). In both local and international works of literature, the focus of using DT in education has been on curriculum and instructional design, solving the challenges of education, improving students' skills, and training teachers. Considering the international literature, it has also been used in organizational development in the educational institutions, design of learning environment, and solving students' problems (Table 1). According to the literature, using the DT approach in education can provide numerous benefits to students and teachers in their learning and teaching (Tran, 2017).

Table 1. The areas using design thinking in the educational context

	International literature	**Local literature**
Curriculum and Instructional design	Tran, 2017	Şahin, 2018
Solving the challenges of education	Loescher et al., 2019	Çetin & Aydemir, 2018
Improving skills of students	Lor, 2017	Atacan, 2020
Teacher training	Diefenthaler, et. al., 2017	Çetin & Aydemir, 2018
Organizational development in the educational institution	Loescher et al., 2019	
Learning environment design	Tran, 2017	
Solving problems of students	Shadow a student, n.d.	

As an innovative and creative process, DT's approach to problem-solving can serve the purpose of STEM education that focuses on inquiry-based, creative, and hands-on learning (Reinking, &

Martin, 2018). International literature indicates that the DT approach is used to train teachers to integrate STEM education into school (Diefenthaler, et. al., 2017), and evaluated under student-centered pedagogies used in STEM education (Ellis et al., 2020). In both works of literature, it is also utilized as a problem-solving process in the STEM program, and K-12 education (Diefenthaler, et. al., 2017; Şahin, 2018; Atacan, 2020).

In the literature, there are multiple DT approaches that involve several steps, design practices, or methods. Although there are some similarities in the number and the name of the process stages, the typical DT approach has three to six stages, and they are based on human-centricity, interdisciplinarity, ideation, and experimentation (Efeoglu, Møller, Sérié & Boer, 2013). Among these approaches, Brown's DT approach as IDEO's method of working with design and innovation can be regarded as a milestone due to being forwarded as a problem-solving process that can be used by everybody, not just designers (Brown, 2008). Brown (2008) divides the DT process into three primary stages. In Brown's method (2008), while *inspiration* means researching to understand the problem and identify the insights, *ideation* means generating ideas, developing them through prototypes, and testing the possible solutions. The last stage of *implementation* means developing an action plan to put the solution into the market.

Three DT approaches are mostly used in the education context: d.school at Stanford University, HPI's (Hasso Plattner Institut), and IDEO's (Design thinking for Educators) DT approaches. The DT process, used since 2005 at the d.school at Stanford University (n.d.), consists of five stages: *empathy, define, ideate, prototype*, and *test*. The DT process, used at HPI (Hasso Plattner Institut) (HPI, n.d.) since 2008, has six stages: *understand, observe, point of view, ideate, prototype*, and *test*. The DT process, used since 2012 in IDEO (Design thinking for Educators) (2012), includes five stages (*discovery, interpretation, ideation, experimentation,* and *evolution*) and a zero-step (*define a challenge*).

When illustrating these three DT approaches under the Brown (2008) three-stage process (Table 2), it is discovered that all DT approaches have similar stages based on Brown's method. The main difference is based on whether having the *implementation* stage in which the iterative process of developing solution is ended. For example, only IDEO (2012) has the *implementation* stage, while others have only *inspiration* and *ideation* stages. HPI also has a DT process in which three steps (*ideate, prototype, and test*) are the same as the d.school process. Moreover, in the three DT approaches, the functions of the stages are similar despite having different names, and some of them being separated into two parts. For instance, the *empathy* in d.school and *discovery* in IDEO have nearly the same function, but, in the HPI process, the role of these stages is divided into two as *understand* and *observe* stages. The function of IDEO's *experimentation* stage is also divided into two; both in HPI and d.school processes as being a *prototype* and *test* stages. It can be concluded that DT approaches executed in the education field have similarities with each other except having changes about the names and the number of the stages. Compared to Brown's approach, having more stages makes the DT processes more tangible for people with a non-design background owing to the division of functions.

Table 2. Comparison of d.school, HPI, and IDEO design thinking approaches considering Brown's design thinking approach

DT Approach	Stages of Design Thinking						
Brown's (2008) DT approach	**Inspiration**			**Ideation**			**Implementation**
	Researching to understand the problem and identify the insights			Generating ideas, developing them through prototypes, and testing possible solutions			Developing an action plan to put the solution into the market
d.school's DT approach (d.school at Stanford University, n.d.)	**Empathy**		**Define**	**Ideate**	**Prototype**	**Test**	
	Empathizing with the people you design to understand what is crucial for them, and how they interact with their environment		Synthesizing the collected data into needs and insights to define a problem statement	Generating multiple ideas	Turning ideas into physical forms through prototypes	Getting feedback from the users about the prototype and developing it to reach better solutions	
HPI's DT approach (HPI, n.d.)	**Understand**	**Observe**	**Point of View**	**Ideate**	**Prototype**	**Test**	
	Collecting data related to the theme/ problem through research	Developing an understanding of the problem and users by doing qualitative research	Sharing of the knowledge collected in the previous stages, combining them to identify needs and insights, and reaching a problem statement by developing a point of view	Developing ideas by brainstorming on the question generated during the POV stage, and selecting the best ideas	Building the selected idea through prototypes	Getting feedback from the users for the prototype, and revising it or the whole concept to reach better solutions	
IDEO's (Design Thinking for Educators) DT approach (IDEO, 2012)	**Discovery**		**Interpretation**	**Ideation**	**Experimentation**		**Evolution**
	Creating a common understanding of the problem within the team by sharing your knowledge, reviewing constraints, defining the target group, and doing qualitative research for collecting data		Transforming the data into insights by sharing and documenting your findings, and making sense of them with identifying themes, insights, and opportunities	Generating ideas by brainstorming and selecting the promising one/ones	Making prototypes, sharing them with other people, and getting feedback about them		Planning further steps for production and documenting the success criteria and the production process.

Exploratory Research

Within the scope of this study, exploratory research has been conducted to understand the challenges and needs of STEM education in Turkey. This part had two phases: conducting interviews with teachers and the school principals and participating in a workshop about STEM education as a participant-observer. In this study, considering both national and international works of literature, STEM is used as an umbrella term to refer to all disciplines.

Phase 1: Conducting interviews with teachers and school principals

To understand the state of the art of STEM education in Turkey, from 14 February 2017 to 24 March 2017, a total of 11 interviews were conducted with school principals, and teachers from several disciplines in four private schools that give STEM, STEM+A, or STEAM education (Table 3). In the selection of the institutions for the exploratory research, their varied approaches to the perception of STEM education were taken into account to get rich data and insights.

Table 3. Institutions and participants in phase 1

School	**Educational Approach**	**Participants**
School A in Samsun (kindergarten, primary school)	STEM	mathematics/science teacher, school principal
School B in İstanbul (kindergarten, primary and secondary school)	STEAM	school principal, science, Turkish and kindergarten teachers
School C in Samsun (kindergarten, primary and secondary school)	STEM	science teacher, school principal
School D in Samsun (kindergarten, primary and secondary school)	STEM+A (STEM with Arts)	visual arts, robotics, and science teachers

Methodology

In this phase, qualitative research methods were utilized, and data were collected through semi-structured interviews with teachers and school principals (Table 4). The interview questions were prepared under four main groups: teachers' understandings about STEM education, the development, and implementation of STEM activities/curriculums, and teacher training about STEM education.

Table 4. Data collection methods in phase 1

Exploratory Research / Phase 1	**Data Collection Methods**	**Number of Interviews**	**Duration of Interviews**	**Date**
Conducting interviews with teachers and school principals	Interview	11	20-45 min.	14 February - 24 March 2017

All interviews were conducted in Turkish, and seven interviews were recorded. The rest of the interviews could not be recorded because the interviewees did not give consent. These interviews were recorded by taking quick notes during the interview, and the notes taken were reviewed after each interview. In phase 1, the duration of the conversations was between 20 to 45 minutes.

To start the analysis of the data, the digital audio files of all interviews were transcribed and organized into individual folders under the name of schools. The school names were coded as "School A" or "School B" to hide their real names. Then, the data has been analyzed based on

the template analysis method which is a style of thematic analysis. The core of template analysis is developing a list of codes representing themes defined in the data (King, 2004). In this research, the initial template was defined based on the interview questions as follows:

- What STEM education means for teachers
- How STEM activities/curriculums are developed
- How teachers learn STEM education
- How STEM education is implemented in Turkey

Starting with the initial template, the data were coded through a computer-assisted qualitative data analysis software, MaxQDA. During the process of coding, the revision was made on the initial template. For instance, under the main code of "What STEM education means for teachers", it was first discovered that non-STEM disciplines are included in STEM education. Later, it was understood that this integration is made either purposefully or unconsciously because some teachers realized that they included non-STEM disciplines in their activities while talking about the activities they implemented (Table 5).

Table 5. The evolution of the coding process

What STEM education means for teachers		
including non-STEM disciplines	• including non-STEM disciplines purposefully 1. "S" in STEM means all disciplines in Turkish translation 2. the engineering design process is the "Art" side of STEM education 3. the visual arts are integrated into STEM purposefully • including non-STEM disciplines unconsciously	including non-STEM disciplines either purposefully or unconsciously

After reading the text many times, the final template (Table 6) was created, and findings were illustrated by making direct quotations from participants' views.

Table 6. Four pre-established codes with refined sub-codes

What STEM education means for teachers	**How teachers learn STEM education**	**How STEM activities/curriculums are developed**	**How STEM education is implemented in Turkey**
including non-STEM disciplines either purposefully or unconsciously	getting training from the STEM research centers	having a STEM+A curriculum • collaboration: revising and developing STEM+A curriculum collaboratively with teachers of the same discipline in all schools	implementing STEM education in which discipline integration is organized around a common theme

the perceived characteristics of STEM education by teachers	collaboration: getting training/assistance from the STEM experienced teachers	collaboration: creating, revising, and developing STEM activities/projects with all teachers or STEM/STEAM experienced teachers	implementing a STEM+A curriculum
	self-education		implementing project-based STEM education under a club activity
	getting in-house education		implementing the story-based projects through books with team teaching (collaboration in teaching)
			teaching the lessons with problem-solving activities
			utilizing the engineering design process as a problem-solving process
			the challenges of implementing STEM education in Turkey

The Findings of Phase 1

What STEM education means for teachers

The findings indicate that the representation and visibility of disciplines vary in implementation. It was observed that in some cases the disciplines were "there", but they were not integrated purposefully by the teachers. For example, the science teacher at School C claimed to implement STEM education by focusing on four STEM disciplines. Upon my question about whether he uses non-STEM disciplines in his activities, he recalled that he facilitated a discussion between medical doctors and students in one of his activities and realized that topics from Turkish literature were already integrated into the activity. He also remembered another activity in which English as a foreign language had also an active role in students' presentations about the solar system.

For School A and B, "S" in STEM represents all branches of science. This perspective may be due to the translation of "S" or "Science" (*Bilim* and *Fen Bilimi*) into Turkish since in Turkish, it means both "all branches of sciences" including formal, natural, social, or applied sciences, and "natural sciences" including physics, or biology. According to the science teacher in School B, the engineering design process is the "Art" side of STEM education because it includes drawing and modeling activities. School B prefers to call it STEAM instead of STEM. Furthermore, in School D, the visual arts are integrated into STEM education purposefully and called STEM+A. As a result, whether it is called STEM, STEAM, or STEM+A, non-STEM disciplines are included in STEM education in these schools. This finding also verifies the related literature about the tendency to incorporate non-STEM disciplines into STEM education (NSF, 2015; Ministry of National Education, 2016).

In the United States, "S" in STEM is handled as "science" and it includes all branches of sciences, therefore the visual arts are also involved in this. They approach it holistically and I believe that it is the right way. While we are practicing this here, we have the same mindset. We name it "STEM". According to the training we received, and academically indeed, STEM does not include art; it includes four basic disciplines (Science, Technology, Engineering, Math). But in Turkey, so in the Turkish language, the letter "S" referring to Science in STEM has alternative meanings: "Science as all branches of sciences" and "Science as natural sciences". (Science/Mathematics teacher in School A)

Art itself takes place in STEM, however, the school administration told us to consider "art" additionally. We primarily attempted to achieve "STEM" but then we realized it was "STEAM" what we already practiced. In other words, it was for including "art" in this process. To conclude, the ones practicing STEM state that STEM already includes "art" and engineering of this process means the field of art. Yet, our school asked for emphasizing the "art" more. (Science teacher in School B)

Furthermore, the perceived characteristics of STEM education were defined. STEM education involves two types of interdisciplinary collaboration: the collaboration of teachers for preparing and implementing STEM activities, and the collaboration of students during the implementation of STEM activities. STEM education further includes teamwork, hands-on practice, learning by living, inquiry-based, project-based, and student-centered learning.

How teachers learned STEM education?

Teachers in Schools B and A usually receive training from teachers with STEM experience, and from the same STEM research center at University X, in which training focuses on science and mathematics disciplines, code-writing (called robotics), and a maker workshop. Teachers at School A adapt this training by integrating "Art" into STEM education to create their school curriculum. School B also invites STEM experienced teachers from other schools to get assistance from them. Therefore, collaboration among teachers has a significant place in learning how to execute STEM education. In School D, the science and visual arts teachers have no STEM education. However, a robotics teacher, who is also a computer education and instructional technology teacher, takes in-house education every year to learn the changes in the curriculum and the related knowledge about these changes. In School C, the science teacher implements STEM education through self-education or in consultation with friends who know STEM education.

How STEM activities/curriculums are developed?

Except for School D, others do not have a ready-made STEM curriculum. Therefore, teachers create and revise their STEM curriculums collaboratively with all teachers, or they sometimes get assistance from experienced teachers. For instance, in School A, teachers create their interdisciplinary STEM curriculum collaboratively. In School B, a kindergarten teacher assists other teachers in preparing STEAM activities. In School C, teachers prepare STEM activities collaboratively under the guidance of a STEM experienced science teacher. Teachers also contribute to the revision of the STEM curriculum. For instance, in School A, teachers from all disciplines share their experiences regarding the implementation of STEM education in each school term. Then, necessary changes are implemented in their STEM curriculum. Moreover,

School D is one of the schools owned by an educational institution, and teachers of the same discipline in all schools belonging to this institution have regional meetings to define the problems regarding the STEM+A curriculum. Later, the feedback collected in these meetings affects the development of the existing curriculum. As a result, the significance of collaboration among teachers is discovered to create, revise, and develop the STEM activity/curriculum. This finding also confirms the literature pointing to the need for teachers' collaboration for the implementation of STEM education (Margot & Kettler, 2019; Akgündüz et al., 2015).

How STEM education is implemented in Turkey?

There are variations at schools in terms of the STEM integration to their education. Discipline integration in School A is organized around a common theme across different disciplines. For this reason, concepts are taught simultaneously in different disciplines/lessons under a common theme.

> *The students are now taking life sciences lesson, in other words, purely "science" lesson; -I am pointing out this for primary classes-, they are being taught this subject in this lesson because it is common with the one which is taught in a music lesson. To exemplify, if the subject "the family" has been taught in life sciences lesson, then a song about the family in a music lesson, a drawing about the family in a painting lesson, and a course about the number of family members in math class are being practiced. (Science/Mathematics teacher in School A)*

All schools implement project-based STEM education under a club activity that aims to enter competitions. According to the robotics teacher in School D, these competitions consist of two parts. The first part is the project part that includes defining and solving a problem by students, and the second part is called robotics and includes code writing under the given theme by using Lego sets. In School B, the story-based STEM projects are also executed with team teaching. In these projects, discipline integrations are made through books of Turkish, English, and social science lessons which have similar or parallel subjects in their contents. Teaching lessons with problem-solving activities based on STEM education is further implemented with individual teaching in science and math lessons. In kindergarten, discipline integration is organized around a common theme. School D also uses its own STEM+A curriculum in the lessons. Moreover, STEM education in School C is implemented in the teaching of science lessons with problem-solving activities.

> *We are going forward with story-based projects instead of lessons in secondary school. The subject in the social science lesson of secondary classes was "Anatolian Civilizations". The sites of Anatolian civilizations and their historical genealogy were taught with their mathematical aspects, then the "Technology" discipline continued with researching in a computer lesson. Also, the students realized the engineering process by trying to build up their prehistoric cottage in the drawing and painting studio. They wrote and performed a theatre play for art and literature. In this play, they were inspired by ancient civilizations and they designed costumes and so the art as a discipline was exhibited with the story of the play. (School Principal in School B)*

Moreover, it was discovered that the engineering design process as a problem-solving process is mostly utilized in STEM activities. According to teachers, it includes problem definition, researching, designing, evaluating, and testing a product, and iterating the entire process until reaching a final product.

Teachers further indicated some challenges for implementing STEM education. First of all, due to the existence of national exams and curricula, teachers have to allocate extra time to collaborate in planning and implementing STEM education, particularly for the use of technological tools in STEM projects. Additionally, the changing role of teachers from implementer to guide has been considered as a significant issue to be addressed for the implementation of STEM education with younger students. Having less educated teachers about STEM education is further stated as one of the problems of implementing STEM education. During the interviews, the differences in technology perception in STEM education were also discovered. For example, for some, incorporating technology into STEM education involves using an online program to make a quiz, create a research journal, or research for a project, while for others, it involves using scissors when building a model. Furthermore, the Turkish and Social Sciences teachers consider STEM education difficult since they cannot figure out how to create activities or projects, and how to integrate technology in STEM education. This finding also confirms the relevant literature on the uncertainty of technology use in STEM education (Ellis et al., 2020).

Phase 2: Participating in a workshop about STEM education as a participant-observer

The second phase of the exploratory research involved attending a two-day STEM workshop as a participant-observer on March 04-05, 2017 to gain insight into the teacher training delivered at the STEM research center. The workshop was organized and facilitated by a research assistant at Y University STEM research center in Ankara to teach science teachers STEM education and the engineering design process as a problem-solving process. There were also mathematics and primary school teachers in the workshop. The workshop participants were approximately 40 teachers who work in primary or secondary schools in Turkey. On the first day of the workshop, there were also four engineers from diverse disciplines to introduce engineering. In this two-day workshop, I aimed to observe how STEM education is taught, how the activities are implemented on teachers, the reactions of teachers and difficulties that teachers faced during the workshop, and the implementation of the STEM activities. Although I participated in the workshop as a participant-observer, I had the chance to have interviews with two teachers who participated in the workshop during the breaks.

On the morning of the first day, engineering and STEM education were presented by the facilitator. Later, a facilitator-led discussion took place among four engineers and teachers on engineering and its place in education. In the afternoon, the first STEM activity to design a weightlifting mechanism based on the working principle of a wind turbine was implemented by the facilitator to teachers. After the presentation of the results of the first activity given by teachers, the first day of the workshop ended. On the second day, a presentation including the engineering design process as a problem-solving process was given. During the presentation, there was a discussion between the teachers and the facilitator about the implementation and challenges of STEM education. Later, the second activity was implemented on teachers to

design a space vehicle that would carry both astronauts and weight while descending from the ramp. The workshop ended after the results of the second activity were presented by the teachers.

Methodology

In this phase, data were collected through participant observation, discussions of teachers among themselves and with engineers, and interviews of two teachers (Table 7). The interview questions of phase 1 were asked in teachers' interviews in phase 2.

Table 7. Data collection methods in phase 2

Exploratory Research / Phase 2	Data Collection Methods	Number of Interviews	Duration of Interviews	Date
Participating in a workshop about STEM education as a participant-observer	Interview, Discussion, Observation	2 (mathematics and primary school teachers)	15 min. for each person	04, 05 March 2017

Interviews with mathematics and primary school teachers were conducted in Turkish, and they could not be recorded because interviewees did not give consent. These 15-minute interviews were recorded by taking quick notes during the interview, and the notes taken were reviewed after each interview. Moreover, discussions of teachers among themselves and with engineers during the STEM workshop have been recorded. To start the analysis of the data, the digital files of observations, discussions, and interviews were organized into individual folders. The collected data were analyzed to generate the final template (Table 8) according to the template analysis method by using the previous initial template and following the same data analysis procedure in phase 1.

Table 8. Four pre-established codes with refined sub-codes

What STEM education means for teachers	How teachers learn STEM education	How STEM activities/curriculums are developed	How STEM education is implemented in Turkey
including non-STEM disciplines	implementing the ready-made STEM activities on teachers to teach STEM education	implementing the ready-made STEM activities instead of creating and implementing their own	the challenges of implementing STEM education in Turkey
the significance of engineering in STEM education	providing teachers with STEM education without considering the differences in education level in primary and secondary schools		
the perceived characteristics of STEM education by teachers			

The Findings of Phase 2

What STEM education means for teachers
Considering the findings, the perceived characteristics of STEM education were defined to understand teachers' perceptions about STEM education. Accordingly, STEM education involves teamwork, inquiry-based learning, and two types of interdisciplinary collaboration: the collaboration of teachers for the implementation of STEM education, and the collaboration of students during the implementation of STEM activities. The findings also indicate that non-STEM disciplines are included in STEM education by teachers.

> *STEM includes all branches; not only science or math, they do not stand separately. It involves collaborative work. I think that STEM means improving scientific processes and STEM education can also be used in Turkish lessons. (Primary school teacher)*

Furthermore, the importance of engineering in STEM education was discovered. According to the findings, engineering means creativity, working in teams, offering multiple solutions to a problem, and learning from failure. It was also stated that an engineer should know about inquiry-based problem-solving, interdisciplinary collaboration, and have social skills that include developing empathy for others. Moreover, the common steps of engineering design processes were defined from the findings; problem definition, designing, evaluating, and testing a product, and iterating the entire process.

How STEM activities/curriculum are developed / How teachers learn STEM education
It was discovered that in the teaching of STEM education to teachers, the differences in education levels in primary and secondary schools are not considered. Furthermore, instead of teaching teachers how to create and implement a STEM activity that meets the students' needs, it was observed that teachers are only taught how to implement ready-made activities in STEM education. However, as previously stated, each piece of literature highlights the need to design and implement the STEM activities appropriate to the educational level of students (Bruce-Davis et al., 2014; Uştu, 2019).

How STEM education is implemented in Turkey
Teachers indicated some challenges for implementing STEM education. One of them is to have training programs for teachers that encourage a result-oriented mindset rather than a process-oriented approach. The educational system which cares about the national exams instead of developing students' creativity has also been considered as a significant issue to be addressed for the implementation of STEM education since this issue can lead students to have a result-oriented mindset. Additionally, teachers have difficulties in following the engineering design problem-solving process.

> ***Teacher 1:*** *... But I might have missed it while making the presentation. (**Teacher 2:** There was not any problem, was there?) Yes, nobody mentioned a problem. Everyone is directly solution-oriented. I had priorly videotaped the presentation and I found an opportunity to watch it. During the presentation, nobody told that he/she had a problem, or he/she found a solution to a problem. No one paid attention to this. There was a material to use and it was certain what would be produced from*

that material and what we had to do with it. When everyone was concentrated on this situation, the problem which was probably the most important part was skipped.

Teacher 2: *It is backbreaking to be involved in the engineering design process step by step and practice it. (Discussion among teachers)*

The challenges originating from the needs and basic skills of the younger students were also discussed for the implementation of STEM education. For instance, according to the needs of younger students, teachers reduce the stages of the engineering design process and change the problem definition stage. Considering these findings, getting familiar with students, and defining their needs and skills are found to be important in the STEM activity design and implementation.

I want to talk back as a teacher working with younger children and consumed with this work. I think that we miss out on the basic skills of children. I only want to ask this: Who can sew or fix his/her ripped button? Today, the children in 2nd or 3rd grade are hardly able to dress themselves. So, it is a little hard for them to design and think over discovering a problem since they do not even know the working principle of a simple machine. Thus, I believe that one should consider the designs and skills which are already existing for the younger groups for the implementation of STEM education. These scientific skills are the ones which we mostly skip, and which try to find solutions to such problems: How to fold a dress, how to organize a closet, or how to write in a notebook, etc. (Discussion among teachers)

Identifying needs is also considered significant in the problem definition stage of STEM activity by teachers. Furthermore, the differences in technology perception in STEM education were discovered in the STEM workshop. Teachers also emphasize the importance of the purpose of use rather than using technology as a tool for technology integration into STEM education. This finding also confirms the relevant literature on matching the technology selection with the desired learning outcomes (Ellis et. al., 2020).

Summary of the Results and Discussion

The findings obtained from the literature review and exploratory research revealed that there are different perspectives on discipline integration, use of technology, and which disciplines STEM education includes. According to the findings of the exploratory research, the perceived characteristics of STEM education and the characteristics and mindsets of engineering were identified. When they are compared with the DT approach (Table 9), the STEM and DT approach have shared characteristics, and both include interdisciplinary collaboration, teamwork, inquiry-based learning, human-centeredness (student-centered learning), and hands-on practice. Furthermore, five characteristics and one mindset are common between Engineering and DT approach, these are interdisciplinary collaboration, teamwork, inquiry-based learning, human-centeredness (empathy), learning from failure, and creativity.

Table 9. The comparison of the characteristics and mindsets among STEM education, Engineering, and DT approach (Red color refers to the common characteristics/mindset)

Characteristics of STEM education	**Characteristics and mindsets of Engineering**	**Characteristics and mindsets of DT approach**
interdisciplinary collaboration	interdisciplinary collaboration	interdisciplinary collaboration (Efeoglu et al., 2013)
teamwork	teamwork	teamwork (Efeoglu et al., 2013)
inquiry-based learning	inquiry-based learning (problem-solving)	inquiry-based learning (McGlynn & Kelly, 2019)
hands-on practice	offer multiple solutions to a problem	hands-on practice (Hassi&Laakso, 2011)
student-centered learning	human-centeredness (empathy)	human-centeredness (Hassi&Laakso, 2011)
project-based learning	creativity	creativity (McGlynn & Kelly, 2019)
learning by living	learn from failure	learn from failure (IDEO, 2012)

According to exploratory research, non-STEM disciplines are included in STEM education. However, teachers receive most of their STEM training within a framework that includes only four STEM disciplines, and in the STEM workshop, teachers are not taught how to create and implement the STEM activities. Since most of the teachers do not have the STEM curriculum, they have to create their activities/curricula based on this training. Therefore, teachers ought to learn how to prepare and implement STEM activities on their own, involving both STEM and non-STEM disciplines. The significance of getting familiar with students, their needs, skills, technology literacy, and educational levels are further discovered in the STEM activity design and implementation. The DT approach is described as the integration point of business, design, engineering, and social sciences (Leifer & Steinert, 2014). In that circumstance, as an interdisciplinary and human-centered process, the DT can enable the integration of diverse disciplines into STEM education and assist teachers in developing and implementing STEM activities considering the students' needs and education levels.

The exploratory research indicates that collaboration among teachers has a significant place in creating, revising, and developing STEM activities, learning STEM education, and implementing STEM projects with team teaching. Teachers also have to allocate extra time to collaboration due to the workload of the education system. The DT approach encourages dealing with multiple disciplines to develop innovative ideas (Grácio & Rijo, 2017), and fosters a collaborative culture for teachers (Diefenthaler, et. al., 2017). According to this, as an interdisciplinary, collaborative, and reflective process (Catterall, 2013), the DT can facilitate the collaboration of teachers from diverse disciplines. As it provides a step-by-step process for collaboration, teachers can use their time more effectively.

The exploratory research demonstrates that the engineering design process as a problem-solving process is mostly utilized in STEM education. However, teachers have difficulties in following the engineering design process. They further state the significance of identifying needs in the problem definition stage of the STEM activity. As an iterative process, DT's way of approach to problem-solving is similar to the engineering design process but has particular mindsets that other problem-solving approaches do not have (Diefenthaler, et. al., 2017). For

instance, one of its mindsets: embracing ambiguity, provides teachers and students with a context-based problem-solving process by embracing holistic thinking (Loescher et al., 2019). Moreover, another mindset, developing empathy for people is significant when identifying the needs in the problem definition process. There has been also an inclination of implementing the DT approach in the project-based STEM activities in K-12 schools to teach multidisciplinary collaboration, creativity, prototyping mindset, and innovation by emphasizing its iterative process (Lor, 2017). Consequently, like the engineering design process, DT can take the role of facilitator and binder in STEM education to enhance creativity, skills, and STEM learning of students because of having distinctive mindsets and similar characteristics with STEM education.

The challenges of integrating technology into STEM education, including the differences in teachers' perception of technology, are also discovered in the exploratory research. According to Norton and Hathaway (2015), a teacher with a design-based teacher education can integrate technology into activities because he understands the functioning of tools (2D or 3D programs), their usage and purpose, and suitability for students. Similarly, through the problem-solving process of the DT approach, teachers can easily incorporate technology (online research tools, prototyping tools) into STEM activities at appropriate stages to achieve a specific learning goal.

The exploratory research reveals some challenges for STEM education, such as the changing role of teachers from implementer to guide in STEM education, and the training programs for teachers and the general education for students which encourage a result-oriented mindset rather than a process-oriented approach. Moreover, in Turkey, the technology and design teachers whose course structure is similar to Industrial Design education are proposed to be a mentor for other teachers in the adoption process of STEM education. According to this, integrating a DT approach as a user-centered and creative problem-solving process into STEM activity design and implementation can ease the transition from result-oriented general education to STEM education both for teachers and students. While the DT approach helps teachers to create a productive and expressive learning environment (IDEO, 2012), it can also support teachers, particularly technology and design teachers, by equipping them with skills and knowledge appropriate to their new roles as guides and mentors.

The study concludes that the DT approach can support STEM education and resolve its challenges with its creative problem-solving process (Catterall, 2013). However, DT mostly focuses on recommended techniques and tools that should be applied in certain stages by imitating the designer's way of doing for non-designers (Laursen & Haase, 2019). According to the authors, if a non-designer applies suggested tools and techniques of the 'DT' approach for certain situations without making situated actions, he will probably use his methodological approach based on his expertise because of knowing one methodological approach. In that circumstance, this study suggests that there is a need to develop a customized DT approach for STEM education.

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Ask me if I am Engaged: A Design-led Approach to Collect Student Feedback on their University Experience

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Abstract
Despite being an established practice in Higher Education (HE), the collection of feedback from students, to improve their university experience, has yet to find a unified format. Literature shows that, besides enabling collection of data on aspects of the university journey, feedback collection should also be an engaging experience for students and translate into a learning opportunity. To facilitate students' engagement and enhance their role as shapers of their HE experience, we propose an innovative method for the collection of student feedback that leverages the potential of Design Thinking. Our method was tested in two design-led workshops for 59 Master students in a Business School in the UK. The workshops, a blend of content delivery, and individual and team activities, were framed around designing the university of the future. Introduced and concluded by two purpose-built surveys, the workshops were organised in problem-framing; ideas generation; and prototyping. Enthusiastically welcomed by participants as a unique way to co-design their HE journey, the workshops achieved the triple objective of collecting rich data on student feedback; increasing engagement in participants; and delivering notions about design thinking. In this paper, we report on the workshops and share details for our method to be replicated.

Key words
Design thinking; student feedback; innovative engagement; active learning; design-led workshop.

Introduction
Gathering feedback from students on their Higher Education (HE) experience has become a normal practice for universities worldwide. A decade ago, the Parliamentary Select Committee report in the UK (House of Commons, 2009) concluded with the following student comment: 'What contributes to a successful university experience is an institution which actively seeks, values and acts on student feedback' (p. 131).

There are several instances, across different countries and education systems, of centralised surveys, administered by HE bodies, to collect data on a national or regional level. Examples include the UK Office for Students' National Student Survey (NSS)[1], or the Australian Government Department of Education and Training's Student Experience Survey (SES)[2]. Besides

[1] https://www.officeforstudents.org.uk/advice-and-guidance/student-information-and-data/national-student-survey-nss/
[2] https://www.compared.edu.au/

these, virtually every university collects student feedback in order to improve its service offerings. Student feedback in this sense can be defined as the use of formal processes to collect information from students about the service they receive in HE (Richardson, 2005). This may refer to perceptions about learning and teaching; support (e.g., libraries); environment (e.g., lecture rooms, laboratories, social space); facilities (e.g., canteens, student accommodation, sport facilities); and external aspects (e.g., finance, car parking and the transport infrastructure) (Harvey, 2011).

Extensive research has been dedicated to investigating how to assess student satisfaction with HE, to identify antecedents of quality. Existing research has mainly employed a quantitative approach, with surveys and questionnaires being particularly common (Douglas, Douglas, McClelland, & Davies, 2015). This has led to significant criticism, in particular with regards to some limitations of satisfaction surveys, among which low levels of student engagement (Harvey, 2011). The present study aims at filling this acknowledged gap in the literature, by exploring an original approach to measure students' satisfaction while enhancing their engagement and learning.

Student engagement has been recently unpacked in campus engagement and class engagement (Gunuc & Kuzu, 2015) and its essence related to the interaction that students have with the HE ecosystem (Bowden, Tickle, & Naumann, 2019). Research has identified connections between student engagement and several success factors such as citizenship behaviours (Zepke, Leach, & Butler, 2014), acquisition of real-world skills (Krause & Coates, 2008), and achievement and learning (Holmes, 2015). Student engagement is the basis for *active learning*, which includes 'any instructional strategy that requires students to engage in meaningful learning activities and think about what they are doing' (Barr, 2014, p. 308). Ensuring engagement whilst collecting student feedback should therefore be a priority when carrying this type of activity out.

In this study, we propose a method to actively engage students in providing feedback on their HE experience, whilst ideating possible solutions for the *pain-points* they identify. Our method is anchored in the Design Thinking (DT) approach, which has been recognised as a dimension of *partnership working* (McIntosh, 2019, p. 234) to facilitate student engagement (Dunne, 2016). Stemming from an application of *designerly* thinking (i.e., thinking like a designer) in disciplines and areas that are not typical of design intervention (e.g., business, education, etc.) and by non-designers (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013), DT has seen an exponential growth in recent decades (Brown, 2008), which has not spared HE. To test out method, we delivered two design-led workshops aimed at gathering students' perceptions around their university experience and asking them to design their *university of the future*. The workshops were a blend of content delivery and practical activities, which have also exposed the students to the DT approach, enhancing their learning experience.

Background of the study

The importance of student feedback for universities

It can be argued that students nowadays see themselves as *customers* who are buying a service (Nixon, Scullion, & Hearn, 2018). In this regard, they are becoming more vocal in expressing their perceptions of good university experience in general (Titus, 2008). With this growing

consumerism of HE, universities have become more market-oriented (Baldwin, 1994) and place a great importance on concerns with quality of their service.

HE institutions collect student feedback with the purposes of enhancing the student experience of learning and teaching; contributing to monitoring and review of quality and standards; ensuring the effectiveness of course design and delivery; enabling a dialogue with students; helping students reflect upon their experiences; as part of the teaching and learning process; identifying good practice; measuring student satisfaction; and contributing to staff development (Brennan & Williams, 2004). Despite these important uses, the validity, reliability and quality of student feedback may be questionable (Carless & Boud, 2018). As such, some researchers argue that gathering student feedback has turned into a basic ritual completed at the end of every course, not capturing the real meaning and purpose of such practice (Mandouit, 2018).

Although feedback from students is constantly collected in many institutions, it is less clear whether it is used to its full potential. Indeed, the more data institutions gather, the more cynical students seem to become, the less valid the information generated and the less carefully the student perspective is considered (Harvey, 2011). Church (2008) (as cited in Harvey 2011, 5) noted that 'students can often feel ambivalent about completing yet another course or module questionnaire. This issue becomes particularly acute when students are not convinced of the value of such activity – particularly if they don't know what resulted from it.' Hence, the necessity to fill a gap in the methodological literature on student feedback and by searching for effective student feedback practices that would also provide appropriate levels of engagement.

Approaches to student feedback

There has been a significant growth of, and sophistication in, processes designed to collect views from students. Typically, a common method for gathering feedback is via student ratings of their level of satisfaction and perceptions of learning gains at the end of a course (Samuel, 2019). Though some researchers believe that the most practical and effective method of gathering student feedback is via structured and planned feedback in the form of questionnaires, comprising agree/disagree statements and open-ended questions (Hand & Rowe, 2001), others find questionnaires or any types of surveys as poor ways of collecting student feedback (Harvey, 2011).

Harvey (2011) has identified four reasons for the ineffectiveness of student satisfaction surveys. First, they are indirect and often there is no clear indication to students of the value or use of the data provided. Second, surveys often do not provide a nuanced understanding of student concerns, issues and acknowledgements. Third, due to lack of detailed understanding, surveys usually offer a space for open comments that seem to be in opposition to the generally satisfactory ratings from closed questions. Finally, most surveys do not include questions about how improvements could be made, and students lack the opportunity to suggest their views on this issue. Hence, there seems to be a significant degree of indifference on the student part as the surveys seem to be simply providing, as Harvey (2011) puts it, a legitimation for inaction. Several scholars prefer to conceptualise feedback in dialogic and processual terms (Carless & Chan, 2017; Carless, Salter, Yang, & Lam, 2011; Rust, O'Donovan, & Price, 2005) presupposing feedback as an 'interactive exchange in which interpretations are shared, meanings negotiated'

(Carless et al., 2011, p. 397). This means that institutions should provide students with opportunities to engage effectively in the ways of thinking and practising of academic community where student voice is respected and taken seriously (McCune & Hounsell, 2005; Price, Handley, Millar, & O'Donovan, 2010).

Harvey (2011) suggests that a dialogic and interactive approach to exploring student perspectives may be seen in the form of face-to-face discussion groups within the classroom, *chaired* by the lecturer, a student or an external facilitator. These may be formally-minuted scheduled events or based on focus groups. Discussions may be conducted virtually, through blogs, or webinars.

In addition, Hand and Rowe (2001) argue that gathering student feedback using only one method of collection is not sufficient or effective. Considering student feedback as part of a continuous cycle of evidence gathering, reflection and change, they propose a *developmental approach* to eliciting and using feedback from students. This model suggests collecting a range of data using various methods throughout the academic year. For example, institutions can start the academic year by gathering informal feedback and then use the generated data to create a mid-year questionnaire at the subsequent stage. Further, focus group interviews may be employed to elaborate on issues and propose solutions. The gathered information is then shared with the staff for professional reflection as well as for communicating back to students how their feedback was implemented for practice improvement.

In an attempt to expand existing theory and practice on student feedback practices in HE, the present study aims at analysing how a design-led approach can be effective in: 1) Collecting rich data about students' experience; 2) Offering students an engaging experience in which they identify potential improvements in their journey through HE; and 3) Teaching the students the basics of DT, the approach we selected to conduct this research. The next section will briefly review literature on such approach.

Design thinking and design-led initiatives

Design Thinking (DT) has emerged in recent years as an approach to facilitate creative problem-solving (Brown, 2008), in several areas: from the improvement of services for citizens and other constituencies (service design), through the betterment of products (product design), to the streamlining of existing processes (process design) or customer experiences (UX), the fields of application of DT are potentially endless. Literally, DT refers to *thinking like a designer* and entails utilising design practice and theory beyond the realm of design (Johansson-Sköldberg et al., 2013). Essential to design practice and theory is the concept of human-centredness and the usage of *empathy* as a way to experience users' emotions, hopes and fears, to generate functional and practical solutions that truly reflect users' needs (Liedtka, 2018; McDonagh & Thomas, 2010).

The practice of directly involving end-users in the design activity is called *user engagement*. Similarly, *customer co-creation* indicates the practice, diffused in design-led exercises and service design in particular (Kolko, 2018; Kummitha, 2019), of making the customers of a service (e.g., the travelling public in an airport) protagonists in the problem-solving activity (e.g., the need to improve the concourse experience in an airport). In these practices, creative collaboration is leveraged to produce value between the deliverers of a service and its end-

users, with the purpose of designing or re-designing such service for the latter. User engagement is centred around the assumption that end-users best represent their needs and feelings towards a service, hence their involvement in the design stage increases the chances of success. Engagement fortifies the connection between the designer and the end-users (Chathoth, Ungson, Harrington, & Chan, 2016).

In recent years, DT has gained traction in HE degrees and has been praised as an effective approach to teach, among others, business (Dunne & Martin, 2006), entrepreneurship (Nielsen & Storvang, 2014), and, in general, twenty-first century skills (Noweski et al., 2012). Thanks to its team-based approach and orientation to practical problems, DT improves the classroom experience of both learners and teachers, in particular in the light of the contemporary focus on constructivist learning and teaching (Scheer, Noweski, & Meinel, 2012). Moreover, DT entails student engagement in a series of cooperative activities, which demonstrably lead to information retainment, higher motivation, and increased confidence (Cavanagh, 2011).

Several schools of thought have conceptualised DT as a process composed by various steps (Liedtka, 2015). In all, the process starts with one or more phases dedicated to investigating the problems at stake, to frame them in an agreed upon way, before proceeding to ideating solutions, prototyping, and testing them and, where necessary, iterating the process in a cyclical way, to ensure continuous improvement. Research is a fundamental component in the DT process and traditionally employs qualitative data collection methods such as facilitated workshops, user interactions, semi-structured interviews and qualitative surveys (Tate, Bongiovanni, Kowalkiewicz, & Townson, 2018).

By virtue of its capacity to engage users in the co-creation process and focus on practical problems whilst utilising qualitative (and, less frequently, quantitative) research methods, a DT approach was utilised to conduct the present research. In this study, we present the results of an innovative method to collect student feedback in an engaging format. Our design-led approach allowed us to address the following research questions:

RQ1: Can a design-led workshop enable the collection of rich data around students' perceptions and feedback on their university experience?
RQ2: Would students like this format and show sufficient level of engagement?
The following section illustrates our method.

Method

In our research, we adopted a design-inspired format that allowed us to collect student feedback whilst offering students an engaging experience and providing them with basic knowledge in the fields of DT and design-led innovation, topics that were not present, at the time the research was conducted, in the course offerings of the Business School.

The University of the Future: A Design-led workshop

We organised two design-led workshops held at a UK-based Business School in April 2019 and February 2020. The workshops saw the participation of 27 and 32 (n=59) Master students, who were primed to an activity which would teach them the basics of DT, together with testing an innovative approach for the collection of student feedback. To do so, the focus of the

workshops was on designing the university of the future by tackling some of the pain-points the students experienced in their journey at the institution. The workshops lasted on average 6 hours each. To offer students a partial reward for their voluntary participation, the workshops were counted against the extra-curricular activities the students had to engage with, to achieve an extra-curricular award. Research shows that extra-curricular activities have a positive impact on the live student experience (Buckley & Lee, 2018; Stuart, Lido, Morgan, Solomon, & May, 2011). Working lunch was also offered. Structurally, the workshops saw an alternation of content delivery on DT by the facilitator and individual and group activities in which the students applied contents, tools and techniques. The research obtained ethical clearance from the business school and students completed their consent forms at the very start of the workshops. Participant information sheets had been shared with the students in the days leading to the workshop, to save time on the day.

First, students were asked to complete a 15-minute survey on their university experience (Appendix 1). At the end of the workshops, they were asked to complete a 10-minute survey on the workshop experience (Appendix 2). To maintain homogeneity in the collected data, format and structure of the two workshops were almost identical, except for some minor variations. Table 1 illustrates the structure and format of the workshops.

Table 1: Structure and contents of the workshops

Content	*Approx. duration (mins)*	*Format*	*Notes*
Activity: Signature of consent forms	2	Individual	Participant information sheets shared previously
Activity: Pre-workshop survey	15	Individual	
Delivery: Introduction to workshop	5	Plenary	
Activity: Icebreaker: One-career goal and one-action Post-It	15	Individual + Group	Drawings only; then presentation (in groups)
Delivery: DT, Basic concepts	10	Plenary	Origins of DT
Delivery: DT as a process	10	Plenary	Schools of thought and stages
Delivery: Problem-framing	5	Plenary	Importance of -
Activity: Pains and gains of your university experience	60	Individual + Group + Plenary	30 minutes activity + 30 minutes presentation (plenary)
Delivery: Personas	10	Plenary	Canvas introduced
Delivery: Value proposition	10	Plenary	Canvas introduced
Activity: Personas and Value Prop (Working lunch)	60	Group + Plenary	40 minutes activity + 20 minutes presentation (plenary)
Short break	10		
Delivery: Ideation	15	Plenary	A selection of ideation lenses presented
Delivery: Storyboarding and Business Model	10	Plenary	Canvas introduced
Activity: Ideation: Design your University of the Future	140	Group + Plenary	70 minutes activity + 60 minutes presentation (plenary) + 10 minutes Q&A
Activity: Post-workshop survey	10	Individual	
Delivery: Conclusion	5	Plenary	

Mirroring trends in postgraduate education, students (n=59) represented around 10 nationalities and 15 degrees/courses, among which the most common ones were international accounting and finance, international strategic marketing and economics. Besides a few exceptions, none of the students had preliminary knowledge on DT.

Results

We present here aggregated findings from the two workshops based on the three main data collection stages/methods in our research: pre-workshop survey (collecting data towards addressing RQ1); workshop activities (RQ1); and post-workshop survey (RQ2).

Pre-workshop survey

Purpose of the pre-workshop survey was to obtain rich, contextual data around students' perceptions of their university experience. This sub-section illustrates our findings.
The first question in the survey asked students, in an open-answer format, to identify what

skills universities ought to teach/develop mainly in the future. Entries were 159 and were coded by the researchers in 43 categories, with the following leading categories: *Communication, public speaking & presentation skills* (18 entries), *Transferable, practice-based skills* (17); *Innovativeness & Creativity* (13). As a follow-up question, students were required to indicate how they thought universities should teach/develop such skills (open answer): students' comments included *guest lectures by practitioners*; *real-world experience*; *field trips to organisations' HQs;* and *better response to student feedback.*

The following question asked students to identify the three most compelling issues they experienced in their HE journey. The 155 entries were coded in 13 categories or 'themes', among which the most popular ones were: *Physical experience in facilities and logistics* (33 entries); *Courses & programmes design and communications* (23); and *Real-world relevance* (21). Similarly, students were required to identify the three most positive aspects of their HE experience. The 121 entries were coded in 8 categories or 'themes', among which the most entries were attracted by *Environment & Atmosphere* (22); *General activities, events & social* (21); and *Teaching & learning* (19).

The remainder of the survey asked students to complete 5-point Likert-scales on their agreement with 27 statements on: 1) general perceptions with regards to their university experience (11 statements); 2) their place in the university (8); 3) their place in the workplace (4); and family pressures' influence on their university experience (4).

In terms of 1), the statements with which participants agreed the most were *universities provide theory-based learning opportunities* (75% agreement) and *universities have the possibility to influence young people's career path today* (71%). The statements with which participants agreed the least were *in 20 years, universities will look mostly the same as today* (63% disagreement) and *universities provide enough internships opportunities* (47%).

As for 2), the following statements were met with most agreement by participants: *students have the opportunity to have a say in how university services could be improved* (78%) and *universities would not even exist if there were no students* (69%). The following ones were met with most disagreement: *I am at university because I need a piece of paper to find a job* (38%) and *my grades are fundamental in my university experience* (17%).

With regards to 3), participants mostly agreed with the statements *I think that the practical knowledge I am getting in my university will be relevant in the workplace* (55%) and *I am studying for a job that will be my job for the next 10 years* (52%). Participants mostly disagreed with the statements *I think that the theoretical knowledge I am getting in my university will be relevant in the workplace* (22%) and *I am studying for a job that will be my job for the next 10 years* (21%).

Finally, with regards to 4), the following statements were particularly welcomed by participants: *my family had a strong role in my decision to go to university* (36%) and *families should be further engaged in the university experience* (28%), whilst the following ones were mostly met with disagreement: *my family will have/had a role in my decision on the first job I will have/had after university* (48%) and *my family had a strong role in my decision to select my degree* (41%).

Workshop activities

After an ice-breaker task, the first activity in the workshop was aimed at helping the groups of participants frame the problems they deemed most relevant, in order to lay the foundations for subsequent ideation of solutions. To do so, groups were asked to first, individually write on colour-coordinated post-it notes as many *pains* and *gains* as they could think of in their university experience; and second, single out the top 5 in each category. Groups were also asked to group top pains and gains in themes. A total of 199 pains (116 in the first workshop; 83 in the second one) and 127 gains (76; 51) were noted by the 59 participants (27; 32). As for the group rankings, themes were similar across the two workshops, with topics including *academics, management, facilities, social events, city, country,* etc., reflecting all the different facets of a university experience. Figure 1 illustrates two examples of artefacts elaborated by two groups in this first activity.

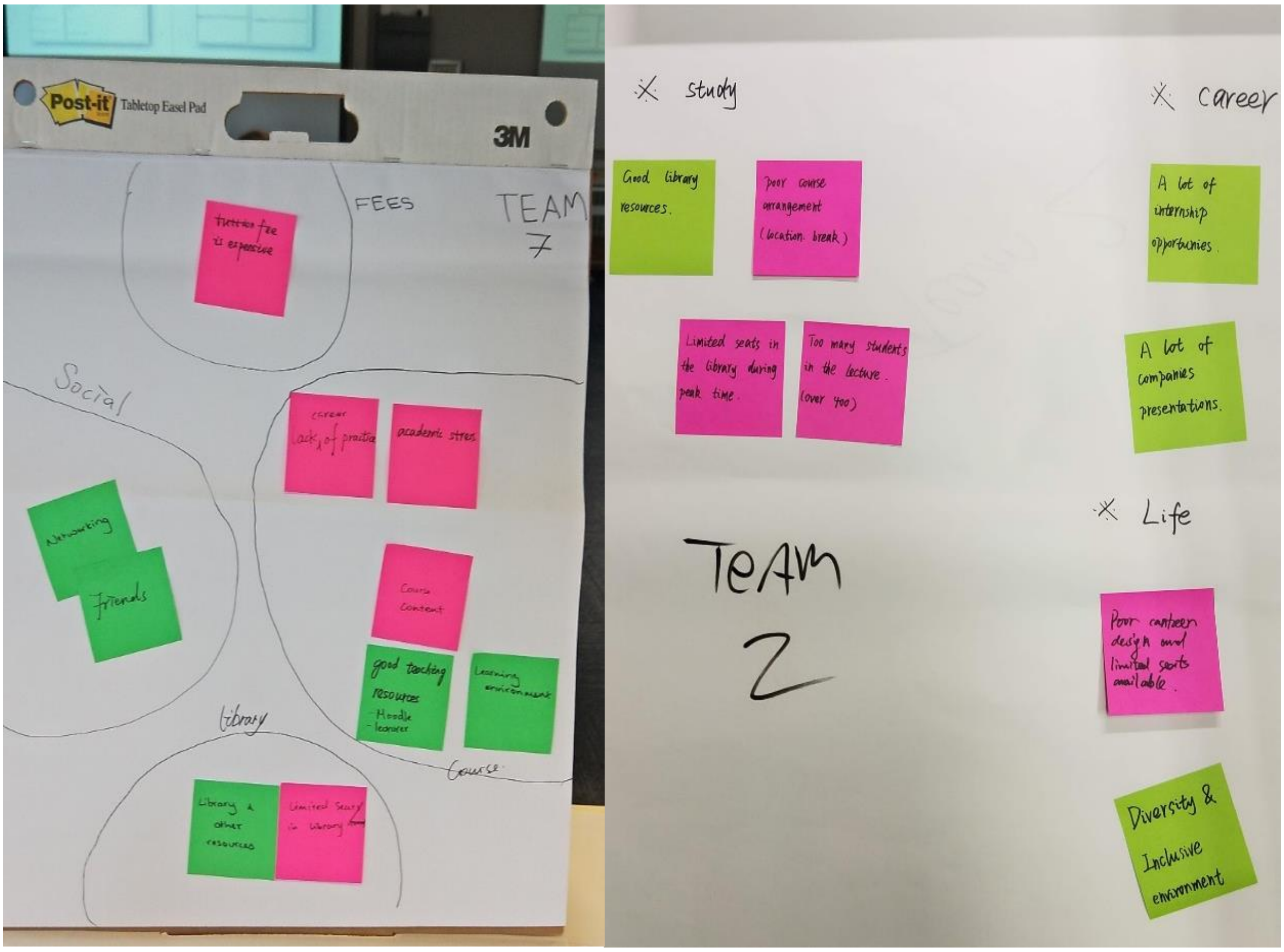

Fig 1 Selection of top pains and gains and theming by two groups

The second activity revolved around *user personas* and *value propositions*. Participants were first made familiar with the concept of a *persona* as a stereotypical representation of a user, classified according to specific dimensions, as a way for designers to materialise whom their solutions should be addressed to. Groups were provided with a purpose-built *persona canvas* (Appendix 3) and asked to complete it, using their reflections and considerations from the first activity. Participants were free to ignore dimensions of the canvas they deemed not relevant or

add missing ones. The following categories and dimensions were proposed in the canvas: *Demographics*, *Personal features*, *Technographics* and *University experience.*[3]

Participants were then made familiar with the concept of *value proposition* as a bridge between problem framing and solution ideation. As for the personas, groups were provided with a *value-proposition canvas*[4] asking them to illustrate *jobs-to-be-done*, *pains* and *gains* and then to produce *pain relievers, gain creators* and *products & services* for their persona (Appendix 4). To exemplify the findings from this second activity, we present the persona and value proposition canvas produced by one team (Figure 2 and Table 2).

Fig. 2 Sample of persona canvas (second activity)

[3] Based on the results of the first workshop, the dimensions top pains and top gains were dropped from the canvas proposed in the second workshop, as redundant.

[4] We utilised an adjusted version of the value proposition canvas available at https://www.strategyzer.com/

Table 2: Sample value proposition canvas (Maria; second activity)

JOB-TO-BE-DONE *(What is the job your user wants to get done?)*	PAINS *(What is annoying or troubling your user? What is preventing them from getting the job done?)*	GAINS *(What would make your user happy? What would make their life and the job-to-be-done easier?)*	PAIN RELIEVERS *(How can you help your user to relieve their pains? What problems can you eradicate?)*	GAIN CREATORS *(What can you offer your user to help them achieve their gains?)*	PRODUCTS & SERVICES *(What are the products and services you can offer to your user so that they can get their job done?)*
Graduation; internship; employability; soft skills	Lack of integration (student-professor-administration); lack of practical experience	Study opportunities; intercultural groups; workshops; supportive administration	More individual meetings with administration; more scholarships; more real case studies; more study-work programmes; incentives for performance	More structured courses and timetable; course description; integration of dissertation & work experience	Online teaching resources; Moodle; career service - focus on international students; career fairs - networking and connections

After completion of the second activity, participants were introduced to a series of ideation lenses (Bongiovanni, 2019; Recker & Rosemann, 2015), as innovative perspectives to creatively solve some of the identified problems. These same lenses were suggested as possible approaches for the third activity: in this, the groups were tasked with selecting one or more *pains* and develop solutions. To do so, besides the ideation lenses, the students were primed to use storyboarding (to illustrate their solutions) and a business model canvas (to help them frame their solutions[5]). The groups were tasked with referring to their persona and value propositions respectively as users and proof-of-value for their solutions. The third activity also included a final presentation of the proposed solutions by each group, in plenary session. The activity concluded the workshop.

The thirteen groups across the two workshops produced the solutions illustrated in Table 3.

[5] We utilised an adjusted version of the one available at https://www.strategyzer.com/

Table 3: Solutions ideated by the 13 groups

Group (random #)	*Solution*	*Addressed problem(s)/opportunity(-ies)*
1	Accelerating Future: a partnership between the university and employers to partially fund tuition fees	Connection between industry and graduates; job placement
2	New student mobile app: with course structure, connections with alumni, informal discussion, etc.	Barriers to settlement for new students; course design and structure
3	Smart university platform that connects students around the world with partner universities	Lack of synergies and connection among universities; university-family connection
4	Global network of universities and employers including real-world projects commissioned to students and sharing of online courses across universities (MOOCs)	Lack of synergies and connection among universities; job placement
5	Mixed on-campus/off-campus course experience	Financial costs associated with on campus study mode; cultural barriers
6	Online study mode with in-company training that leverages AI	Financial costs associated with on campus study mode; affordances of digital technologies
7	Safety and room finding mobile app	Room-finding; difficulty with navigating the campus layout; logistics; safety
8	Smart library: a mobile app for instant booking of free spots	Overcrowded library
9	Space-check app: a mobile app for synched, available seats overview	Overcrowded library
10	Portfolio of solutions to help international students with cultural barriers	Cultural barriers
11	Room-finding and attendance-tracker mobile app	Room-finding; logistics; opportunity for online learning
12	Seat assistant mobile app to track seat occupation on university facilities	Room-finding; logistics; gamification
13	University mobile app with room-finding feature and real-time feedback	Room-finding; logistics; lecturers-students communication

Post-workshop survey

At the end of the workshop, participants were asked to complete one last survey, aimed at assessing their understanding of, and satisfaction with, the workshop. This survey served the researchers to gain an understanding of the level of engagement by the participants (RQ2). The two charts below offer data in terms of participants' ideas, perceptions and interpretations (Figure 3) and participants' satisfaction with the workshop and the proposed approach (DT) (Figure 4).

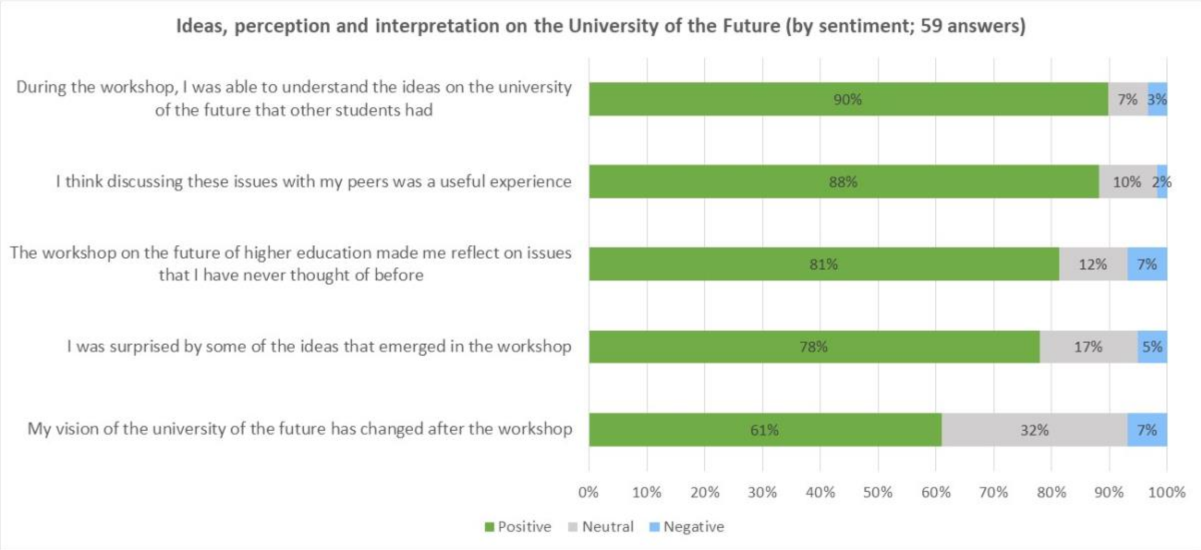

Fig. 3 Post-workshop survey (contents and methods)

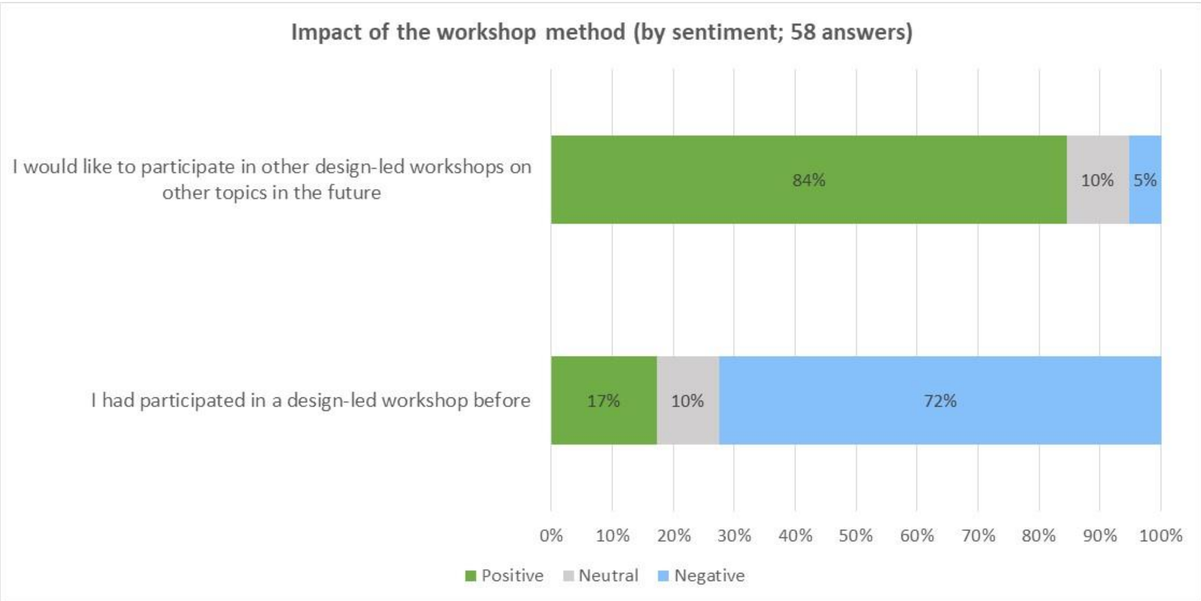

Fig. 4 Post-workshop survey (level of satisfaction by participants)

One last open-ended question asked participants for additional remarks on the workshop. The overwhelming majority of such comments were positive, with regards to aspects such as the method, the facilitation, the lecturers and the level of interactivity (Appendix 5). One only comment was negative, with no further explanations as for why. Suggestions for improvement included reducing duration and parts of delivery vs. activities.

Discussion

At the beginning of our investigation, we posited two RQs:

RQ1: *Can a design-led workshop enable the collection of quantitative and qualitative data around student perceptions and feedback on their university experience?*

RQ2: *Would students like this format and show sufficient level of engagement?*

As for RQ1, the approach we propose in the present paper mixes quantitative and qualitative methods for the collection of student feedback. This enables a richer understanding of students' perceptions around their university experience but can be shaped to focus on specific components such as study facilities, course design, accommodation, internships and job placement opportunities.

The mixed-methods approach (Creswell, 2014) utilised in our workshops allowed us to collect a significant amount of data on the concept of the university of the future, with participants emphasizing the importance of developing communication, public speaking and presentation skills, by increasing the number of practice-based initiatives. Descriptive statistics could be mainly drawn from responses to the pre-workshop survey.

Despite a focus on university and HE in general, participants mainly utilised their experience at their university to assess the pros and cons of their journey through HE. As a result, location-specific aspects such as usage of physical space, logistics and design of courses emerged as areas for improvement. Likewise, features such as environment and atmosphere, social activities and teaching and learning were indicated as strengths. Unsurprisingly, our data revealed that participants recognize the predominance of theory in universities and that universities are rapidly changing, to the point in which, in twenty years, they will look clearly different from now. Among others, participants acknowledged that they have an opportunity to express themselves around areas for improvement in university services and that, without students, universities would not even exist. Finally, in terms of family role, our data showed that whilst families were important in the decision to attend university, the selection of a specific degree was not equally impacted by the family influence.

In the workshops, group tasks represented an occasion for socialising, which was facilitated by an ice-breaking activity (Weisz, 1990). A crucial component of design-led exercises, the problem-framing phase in our workshops saw participants *vent out* their concerns with their university experience and the elements that they considered the most positive. The fact that a total of 199 pains and 127 gains were identified should not be misleading: the workshops were expressly framed as an exercise to ideate *fixes* to current issues and we believe this has primed participants to adopt a somehow critical approach.

Subsequently, activities such as persona and value proposition canvassing allowed the researchers to *dig deep* in how students see themselves as actors in the university cosmos. Expanding this mapping exercise to dimensions that are apparently not associated with HE (e.g., the short- and long-term goals of the persona) offered a more complete comprehension of the dynamics that students experience. In this sense, consistently with existing literature (Zhou, Jindal-Snape, Topping, & Todman, 2008) foreign participants in our workshops underlined the existence of significant cultural and social barriers, especially upon relocation, that a university needs to cater for, when designing student services.

In terms of RQ2, one of the key strategies to inspire engagement in design-led, facilitated activities is by first explaining the reasons for such activities (as epitomised, for example, in Sinek (2009). Well before the workshops (by means of a dedicated webpage) and at the start of

them, we clarified what the purposes of this project were and stressed the importance for participants to co-create solutions for the problems/opportunities for improvement they identified. Co-creation is in fact an effective strategy in ensuring engagement (Bovill, Cook-Sather, Felten, Millard, & Moore-Cherry, 2016). The alternance of parts of content delivery with practical exercises aimed at enabling participants to apply the learnt contents, and fostered those dialogue and interactivity that numerous researchers have indicated as a necessary component in contemporary feedback practices (Carless et al., 2011).

Furthermore, in order to overcome one of the limits of feedback collected exclusively through surveys, our approach dedicated a significant amount of time to the ideation (by the participants) of responses to the pains/issues identified in the feedback components of the workshops. Students were not simply left with the perception that information was passively drawn from them but had an active role in elaborating innovative solutions to solve problems in their university experience. To do so, ideation lenses (Author, 2019; Recker & Rosemann, 2015) proved an effective technique. For others, free brainstorming was the chosen approach. Feedback on the ideas emerged through the workshops was collected by means of questions that asked how clear the presented ideas were (clarity; 90% of participants agreed ideas were clear), how useful the discussions were (usefulness; 88%), how original the approach was (originality; 81%), how surprising ideas were (surprise; 78%) and the extent to which the workshops changed participants' vision on the university of the future (vision; 61%). Overall satisfaction with the workshops (the crucial feedback component) was assessed by asking participants whether they would participate in other design-led initiatives in the future (84% responded affirmatively; 10% was neutral; 5% said 'no'). Considering that 72% of participants had never participated in a design-led exercise before, we can conclude that the overwhelming majority of them found our design-led approach relevant and effective for providing feedback and laying the foundations for innovative solutions to address some of the identified problems.

Practical implications

Informal conversations with the participants at the end of the workshops highlighted an interesting fact: students enjoyed in particular the possibility of providing feedback on their whole university experience, and not just on a specific subject/course, which is the type of feedback they are usually requested to provide. Our study emphasises therefore the need to complement subject-specific satisfaction surveys with the collection of student feedback on their whole university experience. This could be fruitfully managed, for example, by service design/transformation departments in universities and/or specific schools.
Further practical implications can be drawn from some of the qualitative comments provided by participants at the end of the workshops (Appendix 5). Besides the overall satisfaction with the approach (in particular, its interactive nature), several students suggested some components could be shortened (as the delivery on DT theory and techniques). Providing working lunches was also perceived as a plus in the initiative, and so was the quality of the lecturers-students interaction.

Several recommendations can be made to the benefit of fellow researchers who intend to replicate our approach. First, a balanced mix between delivery and activities is needed, to ensure that, on the one hand, participants acquire sufficient knowledge (in the form of design-led tools and techniques) and, on the other hand, have a chance to apply such knowledge. Second, the ability of the lecturer(s) in engaging the participants should not be neglected

(Carless & Boud, 2018): the approach is designed to foster participation, but the delivery skills of the lecturer(s) need to be up to standard. Third, carefully crafted incentives (in our case, the learning experience and the inclusion in the portfolio of courses for an extra-curricular award) can be considered to facilitate participation.

Limitations and areas for further research

A first limitation of our study was the usage of non-validated surveys to assess students' perceptions and their evaluation of their overall university experience. As for the former, a lack of available instruments in the literature suggested us to design our own surveys. As for the latter, the literature abounds with surveys for feedback on specific courses (IPSOS Mori - Office for Students, 2020; Social Research Centre - Commonwealth of Australia, 2020), but suffers from scarcity of instruments to assess the overall university experience. Moreover, our approach is anchored in the discipline of DT, one of the main purposes of which is ideating innovative solutions to complex problems. This required enough flexibility and a qualitative assessment of the student journey through university, not a quantitative one. Ultimate purpose of such assessment was priming participants into the *solution-mode* and not only gathering data for analysis. In a word, the primary, intended beneficiaries of the problem-framing phase were the participants, not the researchers. Hence, the adoption of a purpose-made survey.
A second limitation of our study was in the relatively small sample of participants across the two workshops (59), which could affect the generalisability of our findings. We invite fellow researchers to replicate our study in order to extend the sample and verify results and we are available to provide support on this.

Conclusion

In this study, we adopted a design-inspired format to collect student feedback on the university experience, enhance students' engagement with the provision of such feedback, and provide them with basic knowledge on DT. This allowed us to shape an exercise that made the students protagonists in the elaboration of solutions around the pain-points of their experience. Through mixed methods, we collected a significant amount of data on the concept of the university of the future, pros, and cons of students' HE experience both in academic (teaching & learning) and non-academic (social and cultural) aspects, as well as creative solutions for improving the HE journey.

We clearly communicated to the students the purpose of the project before and during the workshop. This, coupled with the way in which we designed the workshop activities, fostered high levels of student engagement. Our design-led approach enhanced dialogue and interactivity, which are recognised as vital components of effective feedback collection.
The results of this study demonstrate that DT can be fruitfully utilised as an approach to collect student feedback on their journey through HE. This, our study demonstrates, would not only benefit teachers and researchers, but also students. At the same time, we acknowledge the need to increase training opportunities for academics willing to adopt DT in their interactions with students. Based on our experience, such training should be practice-based as learning how to run design-led workshops is best done *by doing*. We invite other researchers to join us in testing our approach, with a view to perfect it over several iterations, across different HE systems.

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Appendices

Appendix 1: Pre-workshop survey

University/College/School
logos here

The Future of Higher Education

Pre-Workshop Survey

A. Demographic information.

1. What is your nationality?
2. What is your study area?
3. When are you supposed to graduate?
4. Where and in what role/industry/job do you plan to work after graduation?

B. Your perspectives about the future of higher education.

1. What skills do you think universities will need to teach/develop in the future?

2. How do you think universities should teach/develop such skills?

C. ***Current and future state and opportunities/problems of universities.***

1. Identify the three most compelling problems that universities face today:

   a. ______________________________

   b. ______________________________

   c. ______________________________

2. Identify the three most positive aspects of universities today:

   a. ______________________________

   b. ______________________________

   c. ______________________________

3. To what extent do you agree with the following statements (tick one box per statement):

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	Universities provide students with just the right skills they need to succeed in the workforce					
2	Universities make the learning experience entertaining and fun					
3	Universities manage to strike the right balance between teaching real-world skills and providing theoretical foundations					

4	Universities provide practice-based learning opportunities					
5	Universities provide theory-based learning opportunities					
6	In 10 years, universities will look mostly the same as today					
7	In 20 years, universities will look mostly the same as today					
8	Other institutions are currently providing young people with more relevant learning opportunities than universities					
9	Universities provide enough internship opportunities					
10	Universities have the possibility to really influence young people's career path today					
11	Universities provide adequate job placement opportunities for students					

D. Perceptions of your place in university.

1. To what extent do you agree with the following statements (tick one box per statement):

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	I feel involved in the activities promoted by my university					
2	I am at university because I need a piece of paper to find a job					
3	My grades are fundamental in my university experience					
4	I think students are the real customers of the university experience					
5	Students have the opportunity to have a say in how university services could be improved					
6	Universities would not even exist if there were no students					
7	I think I take full advantage from my university experience					
#	Statement	Never	Rarely	Some-times	Often	Always
8	I feel engaged in my university life					

E. Perceptions of your place in the workforce.

1. To what extent do you agree with the following statements (tick one box per statement):

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	I am confident I am learning skills to be successful in the workplace					

2	I am studying for a job that will be my job for the next 10 years					
3	I think that the theoretical knowledge I am getting in my university will be relevant in the workplace					
4	I think that the practical knowledge I am getting in my university will be relevant in the workplace					

F. ***Perceptions of family pressures.***

1. To what extent do you agree with the following statements:

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	My family had a strong role in my decision to go to university					
2	My family had a strong role in my decision to select my degree					
3	My family will have/had a role in my decision on the first job I will have/had after university					
4	Families should be further engaged in the university experience					

Appendix 2: Post-workshop survey

University/College/School
logos here

The Future of Higher Education

Post-Workshop Survey

A. *Demographic information.*

1. What is your nationality?

2. What is your study area?

3. When are you supposed to graduate?

B. *Ideas and perceptions before and after the workshop.*

1. To what extent do you agree with the following statements (tick one box per statement):

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	The workshop on the future of higher education made me reflect on issues that I have never thought of before					
2	I think discussing these issues with my peers was a useful experience					
3	My vision of the university of the future has changed after the workshop					

C. *Ideas' interpretation.*

1. To what extent do you agree with the following statements (tick one box per statement):

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	During the workshop, I was able to understand the ideas on the university of the future that other students had					
2	I was surprised by some of the ideas that emerged in the workshop					

2. The idea that I liked the most at the workshop was (describe idea and briefly explain why you liked it):

3. The idea that I liked the least at the workshop was (describe idea and briefly explain why you didn't like it):

D. Other ideas from the day- ones that teams didn't come up with.

1. I wish we had more time to develop one specific idea at the workshop (describe idea):

2. If I were the Ministry of Education and I had unlimited resources, I would further develop the following idea (describe it):

E. The 'impact' of the workshop method.

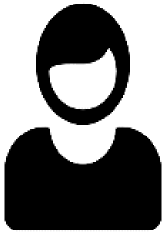
1. To what extent do you agree with the following statements (tick one box per statement):

#	Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	I had participated in a design-led workshop before					
2	I would like to participate in other design-led workshops on other topics in the future					

F. Any final remarks about the workshop?

Appendix 3: Persona Canvas

Persona canvas - Team:



Demographics

Name:
Age:

Nationality:

Relationship status:

Degree (Bachelor, Master, MBA, etc.):

Area of study:

Personal features

Career goal(s):

Hobbies:

Personality traits:

Interesting facts about him/her:

Technographics

Apps mainly used:

What does he/she like about technology:

What does he/she dislike about technology:

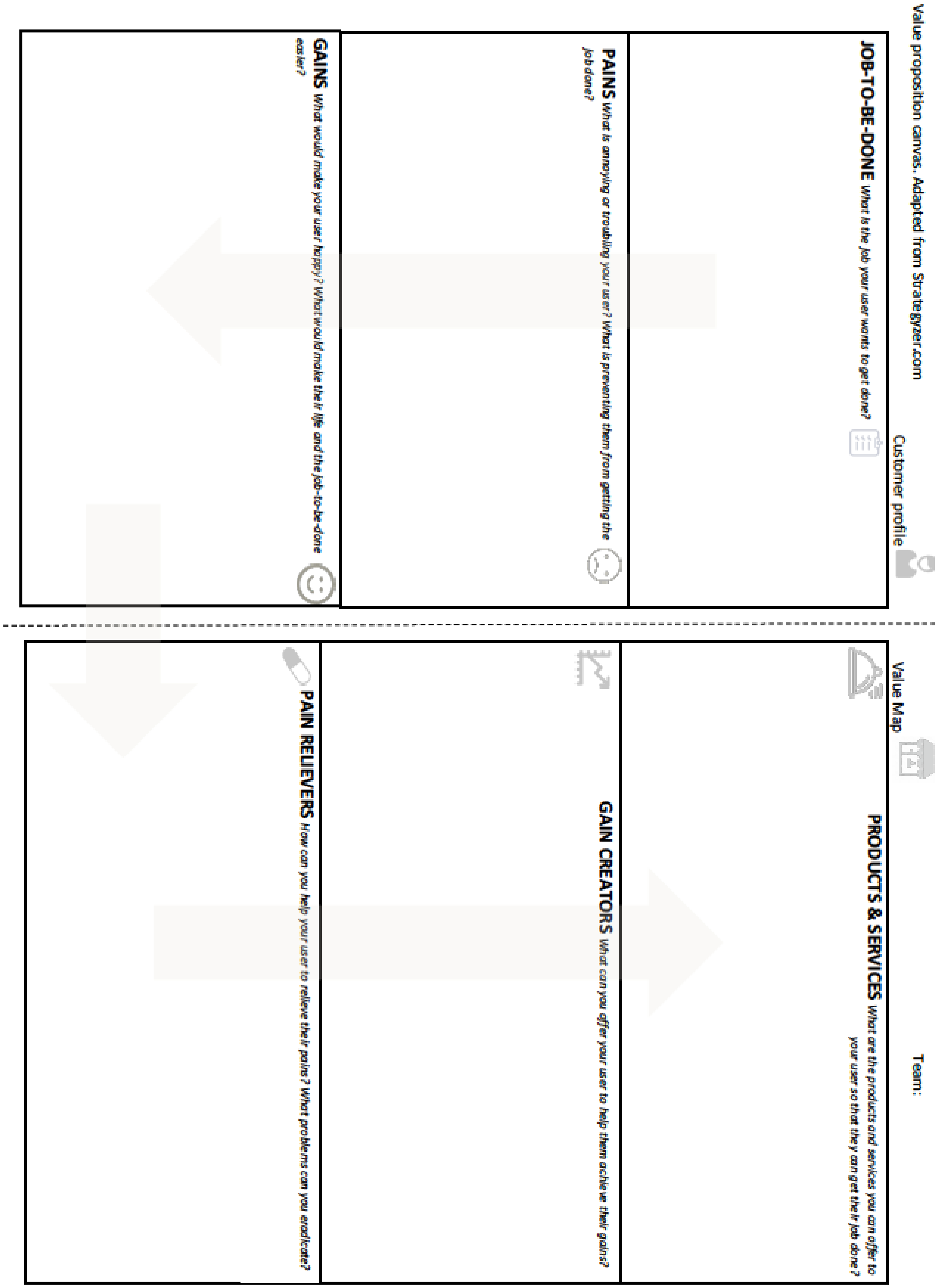
University experience

Main pains:

Main gains:

Feelings towards Higher Education:

Appendix 4: Value Proposition Canvas



Appendix 5: Comments on the workshops

Qualitative feedback on the workshops (from the post-workshop survey, see Appendix 2, question F)

- excellent
- everything was great
- good. Thanks
- presenter was really good and interactive; lunch while working is a good idea
- Thank you for a fascinating and informative course.
- Very thoughtful
- amazing, interesting, highly participation; amazing researcher [lecturer name]
- interesting and amazing
- very interesting, very good food, very nice lecturer, definitely recommended
- Pretty good
- the workshop was amazing and useful
- good!
- great one! Taking each member together by brainstorming
- 8
- thank you!
- it was interesting - thanks!|
- more activities and less lectures
- it is a great workshop, however the time is too long
- good, more activities
- develops creativity and team work; really participative activity!
- great structure, diverse group activities
- good excellent
- so good
- I really enjoyed the workshop, very engaging, good contents and delivery
- no
- interesting and I have a lot of fun thank you
- good!
- really interesting and well organised
- to give me some think about how to solve problems, good method and processes
- chance to take part in a really great workshop with a great instructor
- good, but due to time management some activities are ignored.
- great workshop
- I hope we can engage with everybody in the classroom
- 80/100
- 98 everything is OK
- [lecturer name] was explaining everything very well and clearly as well as in a timely manner.
- it was very interactive and informative. Enjoyed learning so much about design thinking and innovation. Taking back lots of great ideas.
- great host, great activities, overall fun and warming
- I am not satisfied at all thanks for your effort and good luck
- thank you

Design and Technology Education: An International Journal

26.1

An IDEA for design pedagogy: Devising instructional design in higher education 4.0

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Abstract
The purpose of the present study is to constitute a basis for integrating instructional design into higher education 4.0 curricula, aiming at a design pedagogy approach. A conceptual model including the prominent concepts and characteristics of this distinction is suggested with rationales from recent literature. The proposed Instructional Design for Educational Actuality (IDEA) Model uses the dynamics of instructional design and curriculum development processes for higher education and suggests a continuous evaluation and revision procedure. Centering the attention on design issues, the study seeks to advocate for the use of technology in all applicable phases of instructional design process, as is in education 4.0 contexts. Design, development and implementation are the crucial phases of this process, since a design pedagogy approach is followed. The rest of the process, namely analyze and evaluation phases are also subject to design pedagogy, however they are quite individualistic and require a personalized approach. Following technological applications of a symbiotic relationship between instructional design and design pedagogy in higher education contexts, the study ends with a series of implications on stakeholders' roles, concepts-technologies and pedagogical motives.

Keywords:
design pedagogy, instructional design, education 4.0, curriculum development, higher education.

Introduction
The world encounters a global health situation, and in these pandemic times education at a distance is a more powerful alternative than ever before. As learning moves from face-to-face to online, design issues are raised for pedagogical contexts. In this process, the need for an instructional design (ID) policy somehow becomes a compulsory attempt for many countries, as an obvious rapid prototyping model. While people stay in their homes, a tremendous tendency for an instructional immigration takes the stage at the same time. As the ways we retrieve information and transform it into knowledge evolve, many opportunities and challenges come to the fore. For both of these aspects, knowledge-based technological approaches are the prominent concerns since our perceptions of design are changing every day. These changes require revisiting design issues and e-learning pedagogies in different contexts.

Conole (2014) described four categories for pedagogies of e-learning. The first category is called *Associative*, and mainly focuses on traditional associative and reinforcement-based instruction, centring on the individual. *Cognitive* is another category that makes e-learning dynamic, task-based and tries to scrutinize information. *Situative*, the third category gives importance to social presence and interaction, and a self-paced learning. Finally, the last category, namely

Connectivist is a tribute to Siemens' (2004) theory of Connectivism, and advocates a networked learning, specified links for a learning organization and engagement. As a particular type of connectivist and cognitive approach, Grodotzki, Ortelt & Tekkaya (2018) aimed to develop, introduce and evaluate remote and virtual laboratories into higher engineering education. A tele-operative material characterization testing cell was conceptualized and implemented, along with a remote lab for incremental tube forming. Moreover, a Massive-Open-Online-Course (MOOC) was created to make further use of remote labs, and a virtual experimentation lab was developed. At this point, connectivist approaches come to the fore. According to McGreal and Siemens (2012), students in a connectivist MOOC typically perform four activities:

1. Aggregate: Students are asked to pick and choose the content that looks interesting to them and seems to be most appropriate according to their personal learning goals from a wide range of information spilled on the Internet.
2. Remix: Students keep track of the information items they accessed by using any tool from lists offline on their computers to online blogs, Twitter, or the like.
3. Repurpose: Students describe their own understanding of the material they aggregated and remixed before and thereby create new knowledge based on already existing materials.
4. Feed Forward: Students share their thoughts and understanding on the Internet with other course mates and the world at large.

The *Feed Forward* activities here require serious planning and infrastructure. With a similar understanding, both online and offline educational activities require a comprehensive curricular groundwork. Among these, ID can be regarded as the factory floor of many curriculum design efforts.

A well-known ID model, namely ADDIE (Analyze-Design-Development-Implementation-Evaluation) experienced many changes in nearly forty-five years' time. The model was first created for the US Army (Branson et al., 1975) and like many similar processes, continued with organizations and finally educational institutions. Another conception for the model is called instructional systems design, which was first echoed by Watson (1981). Figure 1 summarizes tasks for each model phase:

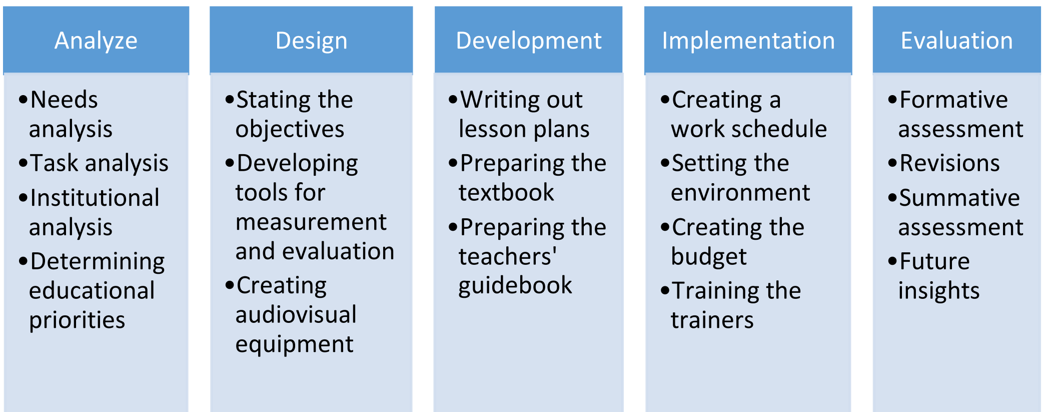


Figure 1. The ADDIE model

Every subphase of the model can be subject to technology integration and the role of an instructional designer here is important to characterize a framework for instructional efforts. The success of these efforts also relies on a comprehensive ID teamwork. The following top-ten-skills were announced by the World Economic Forum (2016) as a forecast for 2020 within the context of industry 4.0 era, which can be also matched with the expectations from an ID team:

- Complex problem solving
- Critical thinking
- Creativity
- People management
- Coordinating with others
- Emotional intelligence
- Judgment and decision making,
- Service orientation,
- Negotiation
- Cognitive flexibility.

An ID team may consist of instructional designers, ID specialists, online learning support specialists, instructional technologists, multimedia designers and/or specialists, researchers, web application developers, teachers, students, measurement and evaluation specialists and many other members with respect to scope and context of the design work. Distinct technical staff are needed and added to the team for the purpose of meeting the above mentioned skills in many cases. Moreover, industry 4.0 understandings require an Internet of Things (IoT) based implementation, which should be originated from a comprehensive analysis of both technology and end users. These analyses provide a good background for educational realities and pedagogical purposes, since more socio-semantic versions of web based education remain on the agenda.

Recent studies expose a tendency to big data analytics, artificial intelligence, augmented reality, cloud computing and internet of things (Ellahi, Khan & Shah, 2019), factors affecting the industry 4.0 adoption in the curriculum of university students' occupation relevance, skills, facility conditions, and social influence impacted on the intermediates variables, namely, relevance advantage, perceived usefulness, behavioural intention-to-use, and actual use (Nguyen & Nguyen, 2020). In the relevant literature, the main components defining education 4.0 are open access, individualized education, mental transformation, integration of digital technologies to education seamless learning environments, lifelong learning, exploratory education and multidisciplinary education (Himmetoglu, Aydug & Bayrak, 2020). For the experiential aspects of these concerns, Knowlton (2016) highlights design studios' role in transforming instructional design and technology because of the continuous use option of studio classes. This option is also important for education 4.0 understandings since they support the use of different types of technologies in the relevant contexts to enhance learning experience.

As an obvious rationale for this study, Tracey and Boling (2014) touch upon a need for descriptions and models for aspects of designing in the field that move beyond process to

describe designers and design teams, the individual activities and tools of design, and the mechanisms of invention. On the other hand, Drysdale (2018) investigates how organizational structures influence leadership over online learning initiatives for dedicated instructional designers in higher education. The results show that decentralized dedicated instructional designers experienced significant disempowerment, role misperception, and challenges in advocacy and leadership, while dedicated instructional designers with administrative reporting lines experienced a high level of role misperception specifically related to technology support. Positional parity between dedicated instructional designers and faculty, in conjunction with implementation of the recommended organizational structure, was found to be critical to empowering designers to be partners and leaders. Moreover, Fredericksen (2017) points out that instructional designers are not widely recognized as leaders, formally or informally, due to challenges in staffing, role perception, and scalability of resources for instructional design teams. In one sense, these realities make their role more important since the rising need for online learning specialists and initiatives is becoming a current concern in these pandemic times.

Purpose of the study

The purpose of the current study is to propose a conceptual model for instructional design efforts in an education 4.0 context, with a design pedagogy approach. The following research questions are sought to be answered:

1. What are the main pedagogical motives for devising instructional design in a higher education 4.0 context?
2. What purpose does instructional design serve for educational agendas and curriculum development?

From an education 4.0 viewpoint,

3. what is the main structure of ID integrated design pedagogy?
4. which technologies are offered to be used in an ID integrated design pedagogy procedure?
5. who are the stakeholders of an ID integrated design pedagogy process?
6. what are the implications for an ID integrated design pedagogy practice?

Significance of the study

Integrating design pedagogy and instructional design is a new and interesting concern, with an education 4.0 understanding. The specific idea of this study is that providing a strong education 4.0 practice lies in a comprehensive ID work, which fits a design pedagogy approach. Moreover, the absence of methodology for the ID oriented design represents a gap in the current literature. The study makes a useful contribution to the existing design pedagogy literature with an ID viewpoint.

This study also provides a series of implications regarding stakeholders and pedagogical motives for a current ID-based education 4.0 practice. In this sense, it may hold significance for instructional designers, researchers and also education policy makers. Instructional designers may benefit from the ID team suggestions while selecting from a wide variety of possible stakeholder groups. Researchers may use the pedagogical motives and the whole model as a

starting point for applied researches, and education policy makers may benefit from the study to monitor education 4.0 in a more comprehensive way.

Methodology

According to Miles, Huberman & Saldana (2014, p. 20), “A conceptual framework explains, either graphically or in narrative form, the main things to be studied and the presumed interrelationships among them”. As a graphical part of this understanding, the present study unpacks design pedagogy, instructional design and education 4.0 concepts to propose a conceptual model for today’s digitalised education. A systematic literature review was conducted on these three concepts, and the following phases were realised throughout the research process:

Phase 1: Conduct a systematic literature review for the current state of the prominent concepts,
Phase 2: Determine recent existing models and frameworks touching upon the idea for integrating ID, design pedagogy and education 4.0,
Phase 3: Seek for a recent model for design pedagogy to integrate ADDIE and education 4.0 centred curriculum,
Phase 4: List the stakeholders for an ID integrated, education 4.0 process aiming at a design pedagogy approach,
Phase 5: List the pedagogical motives for a new conceptual model,
Phase 6: List the most recent technologies suggested for technology mediated education, or digitalised education,
Phase 7: Constitute the new conceptual model and
Phase 8: Pose and discuss the implications for current design pedagogy practices.

For the Phases 4, 5 and 6 the studies in the systematic literature review were grouped with respect to the interrelationships among them. Such methodology helped not only support the model, but also take a closer look into it to pose implications. The following sections present the rationale for integrating design pedagogy, education 4.0 and ID processes with the help of relevant literature.

Design pedagogy

Design pedagogy is a primary knowledge-based approach that bridges technology and pedagogy and poses various opportunities to lead the way for educational technology. One of the earliest uses of the concept of design pedagogy was echoed by Deamer (1999) in accordance with studio pedagogy. Compared to typical classroom scenarios, studios are active sites where students are engaged intellectually and socially, and evaluative modes of thinking in different sets of activities (Dutton, 1984). A similar and newer conceptual approach can be visited within the context of technological pedagogy knowledge which is a component in technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2008). This type of knowledge focuses on the technological foundations and also outcomes of pedagogical efforts, and can be addressed in a philosophical manner, independently of content. However, this is controversial, and in fact a challenge for ID issues since the ID is a standalone process, with no distinction.

Design Pedagogy is originated from Design Thinking (Brown, 2008) and Design-Based Learning (DBL) and provides a look from the learner side of this pedagogical approach. Camburn, Mignone, Arlitt, Venkataraman & Wood (2016) describes some key ideas for DBL:

- Adapt and adopt a Design Innovation or Design Thinking process that is age appropriate, ensuring an environment of creative and innovative opportunities, also open-ended problems,
- Implement a 4D (Discover, Define, Develop and Deliver) Design Pedagogy in the curriculum within and across core subjects,
- Create physical classroom and learning environments encouraging design and creative projects,
- Design and include epitome and capstone projects allowing students to integrate and extend learnings,
- Connect with upper-level programmes and industry for outreach programmes, facilitators, and mentors to initiate and sustain DBL
- Start small and grow a DBL programme across subjects, courses, terms, and co-curricular activities.

Determining learner characteristics is among the most important concerns in a DBL context. Such approach provides information on potential designers' cognitive and psychosocial background which serves as learner analytics for both curriculum and ID.

There are a number of distinct studies touching upon different aspects of design pedagogy and design-based pedagogy (DBP) in a qualitative manner. Exter, Gray & Fernandez (2019) aimed to explore the similarities and differences in the meaning of design for eight faculty members of different faculties. Design definitions included common themes, namely creation of something new, human-centred design focus on problem framing over solution development. The participants were reported not to agree with a strong relationship between design and problem solving and scientific reasoning. Another notable result from the study is that instructional alignment is an important consideration in designing a transdisciplinary learning experience. Since design is an umbrella term and should not always be ascribed to a profession, a number of realities come to the fore for non-designers. Royalty (2018) conducted a study by surveying 27 educators who are non-designers but practice DBP and asked them about the variables they manipulate while creating learning experiences. Then three widely known learning environment frameworks, namely Instructional Design Framework for Authentic Learning Environments, Constructivist Learning Environments and Educause Learning Space Rating System, were compared with DBP. The results of the study show that DBP is more robust than the three frameworks and has a potential in order to have more control over the experiences. Moreover, variables of tone, fun, food, budget and size of class were found to have no connection with the frameworks. DBP is realized to have a standalone strong structure, but sensitive to size of classes. In another descriptive study (Anu, Jorma & Sinikka, 2013), design-oriented pedagogy (DOP) approach was realized through a case study, with 32 multi-age students (aged 6-12). Storytelling videos were analysed and an emerged learning ecosystem was examined. The results showed that inquiry-driven learning tasks and afforded learning

resources guide students to search for strategic types of knowledge to understand the given phenomena and communicate their study processes. The learning ecosystem that emerged in the study includes information resources, technological resources, community resources and an open learning task, each constituting a symbiotic pair with any phenomenon.

Apart from the qualitative studies above, some studies directly focused on field-dependency issues, centred design and did not aim to produce quantitative or experimental data. Acharry, (2014) suggested art-supported and engineering solutions for converting both learning content and technology from 2D to 3D, for pre-engineering students. This solution included four learning stages. An instructor gives a basic lecture on basic art composition with examples from engineering design applications, illustrates architectural model making, assigns students to design 2D works of art, and finally carries out 3D pieces of civil engineering conceptual models. Also, this comprehensive method ends with building up 3D mass models and test process was realized through in-class experiences. With a general outlook on the whole process, such methodologies seem more capable of combining theory and practice. Similar results were found in a study of contemporary art and design practice (Page, 2012) which aimed to enable both beginning teachers and post-age-16 pupils to work together for developing new approaches and strategies within the context of in-class activities. For beginning teachers, the study reported that they have had their identities constructed as artists and designers, and if these two identities are supported, modelled, explored and created beginning teachers' *artist* identity turns into *artist-teacher* and also *learner*.

From an Education 4.0 perspective, a design pedagogy understanding basically constructed on creating cutting edge technologies and also concepts which can be exemplified as cybernetics, robotics, machine learning, big data, nanotechnology, artificial intelligence and global citizenship. More clearly when thinking design pedagogy with education 4.0, concept learning is not centred and a productive pedagogy accompanied by active learning processes is preferred. In one sense, encouraging creativity and design is far more important here. As is known, a higher education student is expected to show an acceptable level of abstract reasoning, creativity and design motivation. Among these, creativity is a primary concept which is used in devising design pedagogy for higher education, and its facets are depicted in Figure 2:

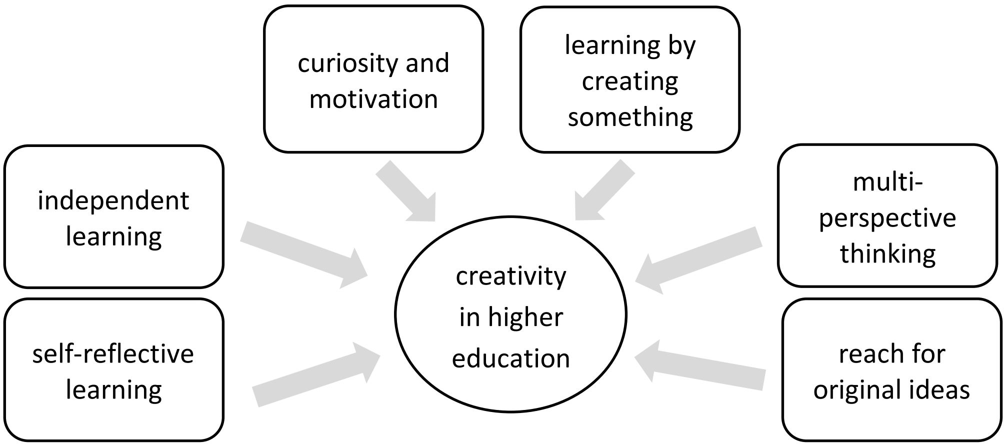


Figure 2. Six facets of creativity in higher education (Terkowsky & Haertel, 2013, p.15)

Multi-perspective thinking leads to multitasking and today each task can be learnt independently. Open and distance education, video lectures and virtualized-adaptive course content which are accessible from all around the world bring out a new learning type that one can call a self-paced, modular learning. Following a design thinking process is crucial here for instructional designers, since non-linear learning occurs during the implementation phase. As the responsibility level of the learners increases, more stable, up-to-date, standardized and interestingly flexible courses are needed, especially for design-based curriculums. Although the term persuasive technology was put into words nearly twenty years ago (Fogg, 2003), the need for changing attitudes and beliefs rises and persuasion has become a standing factor.

Education 4.0 from an instructional design perspective

Innovation interruption that produces education 4.0 that focuses on educational development and skill has made future learning more customized, hyper, intelligent, portable, worldwide and virtual (Shahroom & Hussin, 2018). Education 4.0 offers cutting edge technologies for a digital education, as echoed in this conceptual model. This new face of learning requires a comprehensive system adaption for all countries aiming at innovation. In a recent European Commission report on digital education (Conrads, Rasmussen, Winters, Geniet & Langer, 2017), the following key design principles were addressed for effective system policies:

1. Follow a holistic approach targeting systemic change,
2. Establish both a long-term vision and short-term achievable goals,
3. Deploy technology as a means not an end,
4. Embrace experimentation, risk-taking and failure,
5. Consider the importance and the limits of impact assessment,
6. Involve all stakeholders in a structured dialogue,
7. Let schools and teachers have a say, and
8. Build up teaching competence.

In the similar vein, Gunn (2019) raised a debate for design education in higher education and questions whether it is an academic profession or all about vocational education. In fact, this comparison is about ID processes and particularly implementation phase shows the prominent clues for taking a side. More clearly, an ID team answers this question with their efforts in the field in case the team undertakes both of these professions. Another potential application for implementation phase is constituting digital ecosystems, particularly for e-learning. Recent developments give an impression of a flipped version of learning, with more out-of-school activities.

Digital representation of factory in real time, horizontal integration, data analysis of vertical integration and self-controlling manufacture and logistic are the four stages described for the implementation phase of education 4.0 (Benesova & Tupa, 2017). Digitalization is a key factor in integration and automatization of educational processes for industry 4.0 and opens the gate for implementation practices in a possible ID policy. Also, as Schwab (2018) mentioned, digitalization serves for a possible globalization era after these fourth versions. These digitalization efforts may include both the educational materials and training types for the

actors in the continuum. Digitalization ensures data classification and coherency if a comprehensive scheduling and data entry procedure are followed.

Hussin (2018) suggests recording and editing audio clips, creating engaging video content, using social networking sites to discover new content and grow professionally, using blogs and wikis to create participatory spaces for students, creating engaging presentations, digital portfolios and non-traditional quizzes as the digital skills for education 4.0 instructors. Creating and using virtual and augmented reality, can be added to this list, considering the recent developments in educational technology and also changing expectations from teachers. Also not only creating and using the mentioned technologies are important in education 4.0. Supporting student success is also another prominent factor for the implementation phase of the ID processes, as can be seen in a study conducted by Ciolacu, Tehrani, Binder & Svasta (2018). In this study, an early recognition system was developed and predicted the final score of the students before they take the final examination. The study presents artificial intelligence support as a notable Education 4.0 example. Similarly, focusing on student success in pre-college electric engineering education, Chou and Feng (2019) conducted a quasi-experimental pretest posttest design to investigate how tablet computers influenced learning and success. The results of the study showed that the instructional effectiveness was the same, regardless of whether they used tablet or laptop computer. However, those using the tablet computers achieved greater learning improvement. Similarly Karim, Abu, Adnan & Suhandoko (2018) found that most of higher education believe that mobile devices can help them in learning. The study shows that the students mostly use mobile devices for activities such as discussing course content with classmates, asking classmates questions and exchanging ideas about in-class materials.

Considering the fact that distinct examples of design require more steps and stakeholders, this time education 4.0 produces two sub-concepts, namely learning factory and teaching factory. Mourtzis, Vlachou, Dimitrakopoulos & Zogopoulos (2018) presented a good example of a teaching factory work, which aimed to construct a radio controlled-electric car. Three phases were followed for reaching the final version of the factory work:

1. Participants get to interact with their design, examine it detect any flaws that could drastically affect the final assembly and the functionality of the final solution.
2. The parts of the remotely controlled car are manufactured. Based on their designs, the participants are called to simulate and schedule a production line that will be manufacturing the designed product.
3. An assembly procedure of the final product is realized in two parts. The first part is performed with the aid of a robotic arm, under the human-robot collaboration framework. This process is done also with the help of augmented reality googles. Then a group work is conducted to collect data for the digitalization of the whole process. Finally, each group tests the produced radio-controlled electric car, testing it in a sequence of trials. With all of these efforts, participants acquire a set of highly useful skills that will support their integration in manufacturing.

Apart from teachers, another crucial education 4.0 stakeholder is academicians. Ishak and Mansor (2020) investigated the relationship between knowledge management (KM) and organizational learning (OL) with academic staff readiness for education 4.0. Results showed

that both KM and OL had a significant, positive but weak relationship with academic staff readiness for education 4.0. Capturing knowledge in KM and informal learning in OL are the only predictors for the readiness of the academic staff.

In a recent qualitative study on the role of games, gamification and industry 4.0 tools in education 4.0 (Almeida & Simoes, 2019), 25 case studies of innovative projects in Portuguese higher education institutions were analysed. The results showed that serious games and gamification approaches only appeared in less than 20% of the projects. Stakeholders were teachers, students, university managers and other multidisciplinary fields. A limited number of studies used robotic, video-conference, augmented reality, simulation, cloud computing and system integration. When examined in more detail, the case studies that used the mentioned technologies reported challenges and difficulties especially for little involvement of participants, lack of documentation and simplification of the real world. As can be seen in the study, every innovation has its strengths and weaknesses. Lawrence, Ching and Abdullah (2019) aimed to discuss the strengths and weaknesses of education 4.0 in the higher education institution. Interviews and focus group discussions were addressed and the results of the study showed that education 4.0 creates an opportunity for educators to engage in new technological tools and it promotes the development of technology classrooms to 21st century skills. On the other hand, weaknesses were reported about the role of technology in disconnecting learners from the real world, and a high resistance to adapt and use the education 4.0 technologies due to a belief that these will limit the engagement and involvement of both educator and the student. A comprehensive example for overcoming the claims about these weaknesses, motivation and interaction variables came to the fore. Recent years show a rise in the use of response systems for the motivation problems in education 4.0 applications. However, especially clickers, which are used as remote controllers in these systems, have their own benefits and also disadvantages, as echoed by Stehling, Bach, Richert & Jeschke (2012) in Table 1.

Table 1: Benefits and disadvantages of clickers

	Student	Lecturer
Benefits	interaction without fear of compromising oneself	identification of knowledge gaps
	immediate feedback	identification of shortcomings of the lecture
	checking learning outcomes	student engagement
	be an active participant in class	keeps students focused and involved
	anonymity	higher attendance
	enhancement of learning	better control of the learning progress
	classroom experience more enjoyable	-
Disadvantages	equipment/software functioning	clicker questions take up time pre and during class
	equipment accessibility	the implementation itself costs time and money
	costs occurring when only option of contributing for the student is a text message	equipment/software functioning
	-	diversion by using technical devices in class

As can be seen in Table 1, there are more benefits than disadvantages and these technologies can be accepted and integrated in many instructional contexts. However, technological design and sustainability may become a serious concern when at least mid-tech design issues are not followed (i.e. web support mechanism, database and log management). In recent years anonymity arises, particularly in the Web, and therefore instructional environments will be subject to this new understanding. In fact, prioritizing this need may be beneficial for instructors in the meaning of focusing on the learning outcomes and instruction, independently of student characteristics.

Devising instructional design for curriculum development

According to New Media Consortium's Horizon Report (EDUCAUSE, 2017), 2021 and 2022 were predicted to be important years for robotics and mixed reality, and 2019 Report (EDUCAUSE, 2019) underlines artificial intelligence, blockchain and virtual assistants the most. In fact, all these topics are popular recently, because of the changing needs and beliefs in both learning and teaching. From a robotics perspective, coding and algorithmic thinking are the two crucial point to be addressed. An authentic process should be followed for coding since there are obvious examples in everyday life, like poetry and sign language. A second-order version of this process is customizing these examples for course contents. More clearly, describing only the concepts of variable, character, object and applying them for coding will not be enough for possible robotics work. Such instructional attempts can be described as constructivist in

philosophy, but behaviourist in the lesson. From all reasons above, a systematic, ID-based procedure has the potential to meet theory and practice.

Standardized ID processes are crucial for a sustainable curriculum design in an Education 4.0 context. Standards are not only important for ID itself, they are also important for stakeholders. Shahroom and Hussin (2018) touched on changing landscapes about education 4.0, which are also important for the ID process. These are drawn up as changing landscapes of employment trends, technologies, students' attitude and behaviour and demands. Similarly, Coskun, Kayikci & Gencay (2019) proposed a framework that focus on curriculum, lab preparations and student clubs for adapting engineering education to industry 4.0 visions.

The OECD Learning Framework 2030 (2018) offered a vision for the future of education systems and environmental, economic and social challenges are reported for societies. Individual and societal well-being are central for the shared vision, and digital literacy, health literacy, data literacy and numeracy that are offered for students. Moreover, common concepts for stakeholders are reported as taking responsibility, reconciling tensions-dilemmas and creating new value. A 2030 vision is declared also by UNESCO (2017). A framework of future competencies is developed and seven stable competencies are listed as follows:

1. Lifelong learning
2. Self-agency
3. Interactively using diverse tools and resources
4. Interacting with others
5. Interacting in and with the world
6. Trans-disciplinarity
7. Multi-literateness

In the same framework, competence is claimed to be more complex than skill and that it comprises knowledge, skills, values, and attitudes. The most recurring examples that were reported include:

- Creativity, communication, critical thinking, problem solving, curiosity, metacognition
- Digital, technology, and ICTs skills
- Basic, media, information, financial, scientific literacies and numeracy,
- Cross-cultural skills, leadership, global awareness
- Initiative, self-direction, perseverance, responsibility, accountability, adaptability
- Knowledge of disciplines, STEM mindset.

The above examples show that not only cognitive skills affect competencies, and affective processes should be approached in different cases, from a single course to curriculum scale. In an example of these efforts, Kaplan (2017) aimed to create a short course for teacher training, which provides an overview of issues and theories in technology and education and guides participants into integrating issues and theories into lessons, policies and technology creations. Module 5 in the course content included teaching and learning by design and problem and case-based learning. Lesson plan and project design are the two main tasks in the module and

this model is important since planning and project design are also crucial in ID processes. In addition, STEAM can be added to STEM mindset, to improve designing minds (Keane & Keane, 2016).

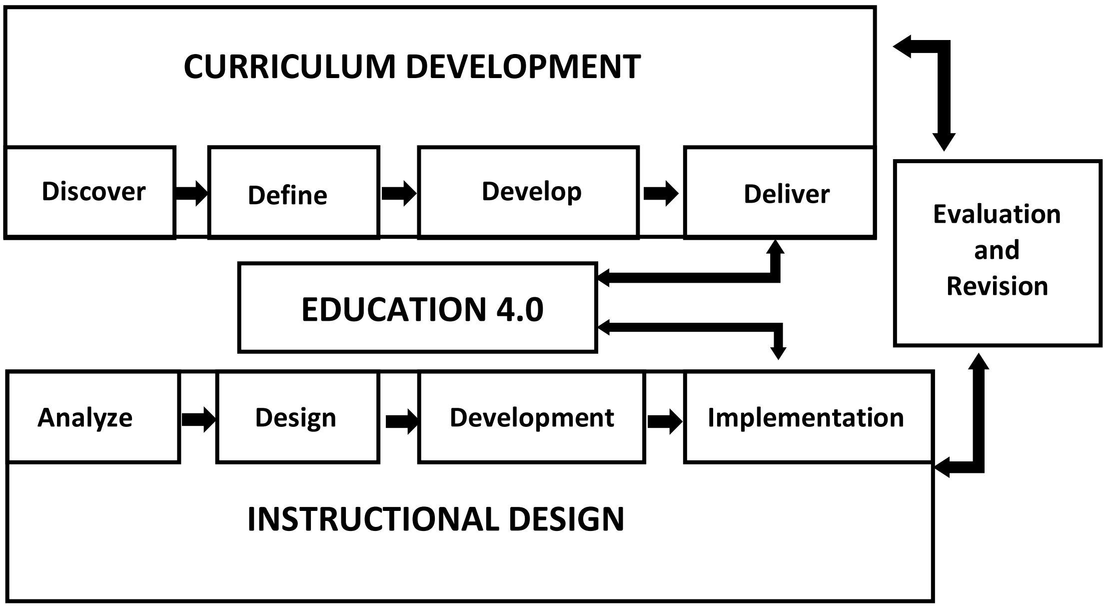
Wark and Ally (2020) proposed an emergent technology integration framework and draw attention to assisting stakeholders in identifying, selecting, and designing educational contexts that cohesively and coherently bind theory with practice from more than one paradigmatic stance. This approach may be quite beneficial for both integrating technology itself, and also for project design as in Kaplan's (2017) proposed course. The proposed Paradigm Shift Framework included reflection phase for behavioural or pedagogical processes, and when a critical reflection gains currency, shifting and an andragogic approach is followed. Finally, for a perceptual or heutagogic approach reflexivity is a prominent understanding. The framework advocated a shift between teacher-directed instruction and learner-determined learning. In a similar vein, Boitshwarelo and Vemuri (2017) proposed a conceptual learning design framework called *The Curriculum-pedagogy Alignment Framework* for contemporary learning environments. The framework aims to bridge between four considerations, namely epistemological, pedagogical, implementation and review. Epistemological considerations included knowledge types (declarative, procedural, contextual, metacognitive and created) and learning processes (acquisition, application, reflection, creation). Pedagogical considerations included pedagogical approaches, strategies and media. Implementation considerations included didactic, activity-based, authentic, complex-dynamic and open-ended learning environments. Finally, review considerations included self-evaluation, student evaluation, peer evaluation and evaluation on the basis of student performance.

A conceptual model

The proposed Instructional Design for Educational Actuality model, or its abbreviated form IDEA prioritises instructional design as a factory for curriculum development, from pedagogy to education. (see figure 3) Educational actuality refers to recent developments and understandings related to educational realities, and an instructional design team is expected to have skills not only in subject or field knowledge, but also multiple literacies to solve current problems. The model focuses on three main dimensions: 1) Choosing the most suitable pedagogical motive for curriculum development 2) Devising ID for curriculum development 3) Delivering education 4.0 outcomes in the field. Design pedagogy is used as an umbrella term for the model, in common with many design & development models. Moreover, pedagogical motives, stakeholders, concepts and technologies were included in order to depict the scope of the model.

Pedagogical motives were selected among the last twenty years' constructivist pedagogies. The rationale for selecting such approaches is that they all serve creativity. The Curriculum Development phase is implemented through aforementioned 4D Design Pedagogy, which is echoed by Camburn et al. (2016). Four phases namely *discover, define, develop and deliver* are used both for the most suitable technology and pedagogical understandings. The rest of the curriculum development process is realized through ID mechanism. Ever so, design pedagogy serves as a bridge between each phase of ID, since the subphases may also require pedagogical design. Finally, education 4.0 structures receive the outcomes that the proposed model

produces, and these can be content, tools, mechanisms, procedures and even ideas for integration. In other words, the term education 4.0 should not only be ascribed to specific technologies and should be approached more broadly.



PEDAGOGICAL MOTIVES
- Design pedagogy
- Studio pedagogy
- Productive pedagogy
- Dialogic pedagogy
- Active pedagogy

CONCEPTS & TECHNOLOGIES
- Cybernetics
- Robotics
- Machine learning
- Big data
- Nanotechnology
- Artificial intelligence
- Mixed reality
- Global citizenship

STAKEHOLDERS
- Students
- Instructional designers
- Instructional design specialists
- Online learning support specialists
- Instructional technologists
- Multimedia designers
- Researchers
- Web application developers
- Measurement and evaluation specialists
- Teachers
- School heads
- District administrators
- School boards
- Parents
- Artists
- Craftsmen
- Engineers

Figure 3. The Instructional Design for Educational Actuality Model

Discussion and implications for current practice

The literature gives a clear impression of a grey zone for technology types and expertise issues in many technology-mediated education studies. First of all, using technology in all applicable phases of an instructional design process raises a debate for making a clear classification of technologies. As a matter of fact, for the implementation and delivery phase of this model web 2.0 platforms may create an uncertainty for medium & media debates on the roles, functions

and capabilities of distinct technologies in learning, since it is difficult to determine which one is the current concern in today's technology integration ideas. Although most of the concepts-technologies in this model are in media category; cybernetics, nanotechnology, and robotics should not be evaluated independent from medium. From a medium viewpoint, web-based platforms can be used as a medium to integrate them into a specific field. This reality makes both instructors and students show an extra effort to learn these platforms and choose the most suitable one among hundreds of them. On the other hand, a socio-semantic version of web provides a background for both Analyze and Discover subphases of this conceptual model. Because semantic web can be used for stereotype student models so that student characteristics can be stored and updated in a sort of live database. The two concepts in the model namely big data and global citizenship are highly associated with these possibilities. Web application developers, online learning support specialists and multimedia designers take the stage here. For all of these aspects, privacy and security issues should be revisited in platform-based, national and global contexts.

Expertise is another concern for discussion. Managing experts from different fields is a challenge for an instructional designer. To overcome time and management issues an interactional process should be taken into account for education 4.0 contexts. Also, systems engineers can be added to engineers' team for outcome management. Such approach is evaluated within the context of Deliver and Implementation subphases. Some flipped course versions including expert videos may provide good examples for bridging industry 4.0 and education 4.0.

Current lists, frameworks and vision documents show that a more independent, personalized and multifaceted learning is offered in today's digitalized education. The success of the IDEA Model primarily lies in facilitating the interaction among the ID team members, making sure that the students know how to learn a distinct technology with a specific purpose and informing also the students about the pedagogical rationales for a current design-based implementation.

The stakeholders list which is originated from the recent literature, shows the massive design pedagogy family itself. Instructional designers are the central stakeholder in the list. To improve current practice, more student-centred approaches are suggested to be implemented accompanied by an interactional structure. This structure may be an online platform to share both ideas and elements of student portfolios.

For technical staff, a possible ID platform should be supported by visualization and programming features. Accordingly, both designing and reporting should be empowered by standalone, cloud aided and conversational agent-based technologies. Design-based platforms are suggested to contain more interactional structures to share ideas and works.

In an IDEA structure, the main role of instructional designers is to conduct task analysis and manage sustainability issues. To achieve these, they are expected to team with researchers, measurement and evaluation specialists and instructional technologists to maintain evaluation and revision processes.

The technologies echoed under the model can be grouped in an education 4.0 context by conducting a comprehensive preliminary ID work. In a small district, interaction effects may be controlled due to urgent planning. On the other hand, when planned in urban contexts accessibility is an advantage to share industry 4.0 opportunities with smaller districts. From an educational perspective, platforms like Edmodo, Google Classroom and Schoology are sufficient for student-student and student-teacher interaction. Canvas, Moodle and Sakai are also subject to powerful interaction, however they are quite massive and in Edmodo parents can easily be added to the stakeholders group. In smaller examples, Edmodo is more powerful for interaction. These platforms are subject to Discover and Define phases and can be approached within the context of e-learning scenarios. On the other hand, a studio pedagogy approach is more powerful for realizing Develop and Deliver phases, which will serve for creativity. Finally, another group is school heads, district administrators and school boards which can be supported with a service orientation and coordination.

Concluding remarks

Technology is a tool in every integration effort. When considered as a purpose or accepted as a unique reference, it has the potential to overshadow learning. Curriculums processed with this manner may not be successful in training and may focus on programming the learners. On the other hand, technology begins to lose its catalyst role in learning. It is being affected by instructional processes and also by various stakeholders implicitly or explicitly. The fact that technology is used in more phases of ID, design pedagogy and even design based research context does not show that it provides a solution to every problem, but shows that it is used more than the traditional methods.

The fieldwork for design thinking, which is an important component for design pedagogy, is realized through STEM and similar applications. Non-digital examples of coding, programming and algorithms can also be adapted into curriculums to show the basics of symbol systems first. Being implemented independent of these understandings, block-based coding and visual programming efforts will be unable to go beyond memorizing drag and drop logic.

Culturally-aware design is another key factor in design pedagogy. Oral and written culture, or in brief, tradition for training becomes a powerful motive, and culturally-responsive design provides, in a sense, a storyboard for ID efforts. In this sense, it is thought that design styles and efforts should also be brought into the forefront to save curriculum development from a highly cognitive structure. For design education contexts, ID efforts are suggested to focus on *analyze* and *design* phases for the intellectual aspects of design work. Specification of educational priorities, analyzing the target group, stating the instructional objectives, assigning the strategies and creating the audio visual equipment are also technologies, when looked at an intellectual side. All the subsequent ID phases are constructed on this intellectual understanding.

As the IDEA model suggests, integrating ID and design pedagogy requires a serious standardization, task analysis, usability and sustainability praxis. It is a challenge to confront more ID phases to integrate technology and standardize them for education 4.0. Thankfully,

this standardization is also an opportunity to better understand the role and timing of technology in pedagogical design issues.

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Book Review

Teaching STEM in the Secondary School: Helping teachers meet the challenge

Banks, F. & Barlex, D. (2021) Teaching STEM in the secondary school: Helping teachers meet the challenge

Reviewed by Andy Mitchell, Independent Consultant, UK

This book explores the purpose and pedagogy of STEM (Science, Technology, Engineering and Mathematics) teaching and the ways in which STEM subjects can interact in the curriculum, to enhance student understanding, achievement and motivation. Publication of this second edition is particularly apposite, considering the current world under COVID 19. As reported daily in the media, STEM is at the heart of providing the solution to the pandemic. Perhaps this represents the most significant ever worldwide bringing together of the individual elements of the construct to address a common goal. In terms of education, this should only serve to promote further the benefits of cross curricular study, working in teams and the benefits to learning in terms of knowledge application not simply acquisition.

Cross curricular working, continues to be an elusive objective in many schools, not helped by the strictures of public examination systems. But the authors argue there has never been a better time to consider new ways of constructing a relevant curriculum. Not least as it this best reflects the world beyond education. 'With regard to interaction between the subjects, it is becoming increasingly clear that the problems now facing the world will need robust interdisciplinary teams for their solution hence an interaction at school level might be a useful precursor. (p.53)

But the book's publication is pertinent for a second reason. From at least a UK perspective of design and technology (D&T) education, coping with the persistent challenge of employing sufficient subject trained specialists, extending design and technology teaching teams to include teacher colleagues with non-D&T backgrounds but related expertise may offer a solution. At a time when D&T is perhaps experiencing its lowest status in its history, the opportunity to use creative timetabling and collaboration with computing, science but also art and design, to revitalise both its teaching and perception, could offers interesting possibilities. Whether or not this way of working adopts the acronym STEM (the use of which is contested in some quarters), securing the fundamental of D&T teaching that makes more formal use of shared knowledge skills and understanding can only be of benefit to learners.

Central to the books purpose, is the proposal that teachers need to look beyond their own subject, to create teaching and learning experiences that make sense of and enrich science, technology and mathematics. Indeed, the problems of siloed organisation of learning which fails to exploit the relationship between different subjects, one could argue has long held back

learning. Chapter 2 refers to this as 'Looking sideways'. But key is the consideration of the silent 'D' for design and the vital role that design and technology plays, not least in providing meaning, context and purpose. Throughout, concepts are explored through each contributory subject. Too often the label STEM is applied incorrectly and frequently describes work that is much narrower in nature than the construct implies and is restricted to mathematics and science. The book provides an excellent justification for STEM but also defines it in much more inclusive terms.

Those who found useful the first edition of the book published in 2014, will not be disappointed by this revision. It has been significantly updated and contains a good deal of additional content.

This book will be particularly useful to schoolteachers, interested in both curriculum development in their workplace and their own personal development. It provides an accessible source to inform their thinking and draws together perspectives from the contributing disciplines, key authors and initiatives that underpin STEM education. It should also feature in indicative reading lists for initial teacher education (ITE), assisting student's development of their ability to draw links between subjects and understand better their own subject's contribution.

The authors share considerable experience of working in various fields, including science, design and technology, teaching in schools but significantly providing teacher education. Barlex in particular has a considerable reputation for his contribution to D&T curriculum development and the publication of resources to support teaching and learning. Perhaps the best known of which is the Nuffield Design and Technology Project (2000); and also, the Young Foresight resource (2000), a 12-week programme for 14-year-olds, making use of industry links and designed to stimulate creativity by challenging orthodox practise in design and technology. The contents of both are referred to for illustrative purposes.

As a text, it also provides a very useful reader for senior leaders and curriculum planners in school, looking for ways to managing and sustain STEM approaches. Even if coming from one of the STEM subjects, it will help them become more conversant with each subject's potential contribution. If a school were to embark on developing STEM an initiative, not least those that have already taken the decision not to include D&T in the curriculum, then this book would provide an excellent introduction to promoting discussion and ensuring a common understanding.

The scenario of entering the post pandemic world to which we hope to return, adds further weight. Even when we return to life more similar to pre-March 2000, the education world will never be the same again. Addressing D&T's precarious position in many schools will depend entirely on its community being proactive, rising to the challenge and embracing the opportunities presented. Whenever we overcome Covid-19 and its variants, we cannot expect a massive investment in education to follow. Many countries including the UK will be financially challenged. Certainly, it is unlikely that D&T will be prioritised. However, in some situation, STEM might be.

The book is helpfully laid out, each chapter encouraging further exploration with the inclusion of extensive and useful recommended reading lists. This alone, serves as a very useful

bibliography for scholars, not least those undertaking courses in ITE. Most chapters also contain a short conclusion and additional reading list. This may help the reader to 'dip into' the book, quickly identify issues of immediate interest to them.

The book is well illustrated contributing to its accessibility. However, the range of figures is largely restricted to diagrams and resources. Difficult though it often is to collect actual examples of STEM outcomes emanating from schools, considering the practical nature and physical outcomes of the type of activity advocated, it is perhaps disappointing these are under-represented. Chapter 9: Computing, digital competence, computer science, TEL and STEM is a case in point. The section: Computing in design & technology and engineering lesson (p.193) provides a comprehensive list of the ways in which IT has massively extended the range and capability of young people working in D&T and in STEM contexts. If photographs of student's application of microprocessors or CAD and additive manufacture, harnessed to facilitate outcomes, until recently beyond the capability of schools had been included, it would have been compelling. This would also have provided opportunity to include contemporary, different and perhaps more imaginative examples of D&T and engineering, the type of which we should be promoting today.

Including separate chapters to consider STEM from the standpoint of each subject specialism may well provide an 'in' for the reader, eager to understand first, how their own specialism is represented. For example, Chapter 7: 'Enabling the 'E' in STEM'.

A welcome new addition is provided by Chapter 11: Looking at STEM education in different countries. In this section authors from Australia, Belgium, Brazil, China, Israel, Russia, Taiwan, and the USA write about STEM education in their particular countries. Each piece has been extracted from a longer piece, all of which can be found at the website https://dandtfordandt.wordpress.com.

What follows are fascinating examples of how STEM education has been approached in each country, which add to the ideas throughout the book, that will provide stimulus for teachers to develop their own activity. The overcoming of challenges reported in scenarios is interesting but also the conveying of a sense of the opportunities created.

In Belgium (p. 240), we read of 'the pedagogical adjustments required to implement the STEM projects imparting a new instructional paradigm on teachers where their concept of learning progression evolved from teaching maths first, using that acquired in science, followed by application in technology, to a more integrative view where interdisciplinary interactions occur in a more natural way (Thibaut et al., 2018).

In China, (p.247) we learn how the Ministry of Education has implemented various educational reform strategies, including practical STEM activity. The scale of the 'China STEM Education 2029 Innovation Action Plan' launched in May of 2018, opens the systematic development of STEM education in China. This is enviable. It will undoubtedly provide useful experience with which to compare practise elsewhere. Although unconnected, since 2014, the D&T Association has been involved in supporting the Ministry of Education's development of design and technology in Shanghai schools, so is very familiar with the interest in and rapid development of design and STEM in parts of China.

Not only is each description supported by an example, but each study includes a section on the future development of STEM education in secondary schools again making for useful comparisons with what could be developed in a teacher's home country, region or individual school.

The final chapter builds on the examples of STEM education illustrated in chapter 11. It is divided into three sections 'Big issues and STEM education', 'STEM education and disruptive technologies' and the final part, 'Your vision' which considers four possible scenarios for the future of STEM. The latter depicts four scenarios from 'axis of uncertainty' described by two crossing continuums: one being isolation/collaboration, the other vocational/general. The authors claim these 'provide an opportunity to explore possible futures from various perspectives and consider the consequences of such futures for STEM education'. At a time when there is a need for design and technology education to consider its own future and the value of its unique contribution to the broader curriculum, this serves as a timely reminder of the dangers of being reduced in some schools, to a subject taught 'in isolation, with vocational education intent'. Not a scenario advocates of D&T would welcome.

Footnote

In the absence of a printed copy, this book was reviewed in E-book form, using the VitalSource Bookshelf computer app. This provides some useful features common with virtual book software including searching, book marking and note making. However prospective readers may wish to wait until paper copy is available. Whilst I would recommend a school owning several copies for its staff development library, for sharing and discussion purposes, a decision needs to be made in the workplace, whether E-book or print copy is the most suitable.

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Book Review

Learning to Teach Design and Technology in The Secondary School: A Companion to School Experience

Hardy, A. (Ed.). (2020) Learning to Teach Design and Technology in The Secondary School: A Companion to School Experience. 4th Edition. Routledge, Abingdon, UK

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Alison Hardy, Editor, is Senior Lecturer at Nottingham Trent University, UK. She teaches on the PGCE Design and Technology (D&T) course and is Lead for the MA Education programme. She is also an author, presenter, podcaster and researcher for D&T.

This is the fourth and fully updated edition in this series of books. The book is aimed at those who are training to teach design and technology in the secondary school. The areas covered include subject knowledge, subject pedagogies, underpinning philosophy and the wider issues that will support an understanding of the purpose and potential of design and technology education.

Although the book purports to be for secondary trainee teachers, there are some chapters that would be useful for all teachers/mentors of design and technology, primary and secondary.

In this publication, Hardy has brought together contributions from practicing teachers, researchers, consultants, writers and academics to share their experiences and insights creating a collection of invaluable resources for those '*who aspire to become effective, reflective design and technology teachers*' (page i). A summary of each chapter as well as powerpoint slides to accompany these chapters have also been created and can be found on Alison Hardy's podcast and blog site: https://alisonhardy.work/teaching-dt/lttdandt/

This book covers all areas of design and technology and is divided into four parts. Each part starts with a brief overview and rational for that part of the book.

Part One: From the history to the present day.

Chapter 1: Design and Technology in the Secondary School by Alison Hardy

For those who are new to design and technology education, Hardy gives an overview of the 30 years history and the subsequent changes in the curriculum content and teaching design and technology as part of the national curriculum in England. The chapter starts with the nomenclature, reinforcing that the subject abbreviation needs to be 'D&T' and not 'DT' and this

differentiation impacts on creating personal rationales and the underpinning to help define the philosophical understanding of how the design and technology curriculum can be constructed and taught well. Hardy takes a global stance to look at 'design and technology' education across other countries and how curriculum across the world have different emphasis. There is an exploration of some interesting ways of looking at 'subject knowledge', 'subject aims' and 'subject epistemology' that still remain as areas of debate in education.

Chapter 2: Design and Technology in the Primary School by Clare Benson

The chapter on primary design and technology is particularly interesting for secondary design and technology teachers. Reading this chapter gives an insight into what children learn in primary design and technology and how the secondary curriculum needs to build on this knowledge to avoid repeating what has already been taught and ensuring that there is progression and challenge in key stage three. Benson goes into detail about the different approaches primary educators takes in developing the curriculum for children to access skills and knowledge across the breadth of the subject in the national curriculum. She also explains the issues of how subject was introduced in primary education and the content of teaching design and technology in an ordinary classroom.

Part Two Design and Technology Curriculum

Part Two covers the design and technology curriculum for secondary schools and here there are some ideas that are useful for primary trainees also. The aim of the content of the first six chapters is to give an outline of the curriculum content of a specific area under the design and technology subject area: designing, materials, textiles, electronics, and food. Some chapters start with a brief history of the subject and this is helpful where there are literature links to follow up on. These chapters go on to list subject content from which the trainee teacher could develop a personal subject audit and identify areas for development, to gain a good subject knowledge. Most chapters refer to examination specifications and some mention the diverse types of exams and their content. Three of the five remaining chapters are new - the role of critiquing in design and technology education, transitions after secondary design and technology, and using and producing design and technology education research.

Chapter 3: Designing in Design and Technology by Paul Woodward

Woodward uses some interesting ways to breaking-down and defining words like 'design and designing' and the relationship with creativity and innovation. Much of the content in this chapter is driven by Woodward's extensive and successful experience of teaching design, designing, and learning to design. There are some outlines of strategies to develop ways of designing and ways in which to promote design thinking to move away from uninspired design outcomes. Many of these could be selected and developed for classroom use.

Chapter 4: Teaching Design Communication Skills by Jamie Tinny and Mike Mellors

Tinny and Mellors start with a brief history of design and communication although the dates or references are not included. There are some helpful suggestions for the concept of designing. Some of the activities in this chapter are thoughtful, particularly the one relating to the exploration of examination specifications. There is some exploration of children's resistance to

drawing and production of unimaginative designs that often challenge teachers of design and technology. The chapter goes on to explore the examination specifications in this area.

Chapter 5: Preparing to Teach Materials Technology by Alan Bright

Bright gives a brief overview of the history that includes some related key developments, including vocational education, that impacted on the content of teaching design and technology. The chapter is easy to navigate, considering the breadth of the subject content in this area of design and technology – materials (old and new), tools and processes and other areas of knowledge that need to be covered are organised and supportive. Knowledge, skills, and understanding are outlined and arranged to the extent that some could be directly lifted for use in the classroom. They could also be used for long term planning and progression both in key stage 3 (11-14 year olds) and key stage 4 (15-16 year olds). There is clear direction of how to use mind maps to generate the breakdown of skills and knowledge. The guide to auditing subject knowledge in this area would be beneficial for trainee and beginner teachers of design and technology. Although not fully covered, there is a clear direction toward sustainability, as well as direction on some of the smaller things that new teachers may not notice. The chapter comments on maintaining engagement and progression through thoughtful activities. Follow up literature is useful.

Chapter 6: Preparing to Teach Textiles by Suzanne Lawson and Heidi Ambrose-Brown

Lawson and Ambrose-Brown explore the place of textiles in the school curriculum and how it can vary from being taught through art and design or design and technology or both. There is the mention of domestic, industrial, and global contexts for the use of textiles and their different applications. The chapter is organised using headings from the design process generally used in the school setting and helpful for medium term planning. Some of the methods, activities and resources can be lifted to use in the school setting. The chapter later moves into key stage 3 and key stage 4 requirements and this would be useful for long term planning and progression in both key stages for textiles knowledge and skills. The subject content and progression are well presented and useful for both experienced and non-experienced teachers. There is break down of subject knowledge, skills and understanding that could easily be used as subject audit documents as well as identifying areas for learning in textiles.

Chapter 7: Preparing to Teach Electronics and Control Technologies by Tony Cowell

Cowell has taken a global approach and so this chapter is written to include many countries that teach control technologies. It starts with the complex and mixed use of the terminology / labels used by various countries and organisations and how these can often be the cause of much confusion, particularly, when trainee teachers and teachers with little experience in this area, start to teach control technologies. The chapter is well organised, easy to navigate and follow as it starts with the basics, progresses to identify three distinct areas of control, and then gradually moves to the more advanced level of teaching control technologies. There are clear explanations and details of the components, processes, and outputs. The skills, knowledge and understanding are organised in tables to show progression from early to later stages in learning for both key stages. There is helpful advice on teaching and managing the knowledge

requirements. There is guidance of managing the practical elements of teaching control and particularly helpful to think of micro and macro aspects of teaching in this area.

Chapter 8: Preparing to Teach Food in the Secondary School Curriculum by Marion Rutland and Angela Turner

Rutland and Turner start with an explanation of the breadth of food teaching in school requiring even the most qualified food expert to read and learn from this chapter as teaching within a timetable slot in a school is quite different to any other industry. Rutland and Turner discuss the differences in curriculum expectation in different countries. There is a brief history of teaching food in schools utilising some useful references. The chapter is easy to navigate with headings that organise the various aspects of skills and knowledge for the teaching of food in schools. It is noticeably clear about the need to understand that designing in food does not involve drawing and explains ways in which to do this with integrity to understanding food. Tables outline progression for key stage 3 and key stage 4 so especially useful for long- and medium-term planning. There are some useful ideas for managing practical food activities in class. The content is useful for trainee and beginner teachers.

Chapter 9: Teaching about Disruption: A key feature of new and emerging technologies by David Barlex, Torben Steeg and Nick Givens

Barlex, Steeg and Givens rationalise how the place of disruptive technologies in the design and technology curriculum addresses the national curriculum programme of study by identifying the requirement to teach '*new and emerging technologies and their impact*' (DfE, 2014). There is good list of disruptive technologies with a clear explanation of each to select from. The examples/analogies used to illustrate some of the disruptive technologies could be lifted straight from this chapter to use in the classroom with children from later key stage 2 (7-11 year olds), key stage 3 and key stage 4. The content is made richer with references used to support the writing and the sources to follow up on. The exploration and explanation of disruptive technologies chapter is easy to access and use. This chapter is worth reading for all teachers – it presents a fresh way of teaching and creating ways of working to engage children, foster curiosity and challenge the norm. It will lead to design and technology departments wanting to up-date their curriculum content to include disruptive ideas.

Chapter 10: The Role of Critiquing in Design and Technology Education by Steve Keirl

Keirl explores the idea of using critiquing to establish a deeper way of knowing, understanding, thinking, and questioning. Although Keirl explains that this is not just about evaluating skills, there is scope here improve on reflective and critiquing skills needed for evaluations. All the same, the clarity of how critiquing is much broader than this is well explored. Reading this chapter will change the way you approach teaching in all areas of design and technology. Children often struggle with deeper thinking and prompting them to analyse, evaluate or question, can be either a big challenge or sometimes result in pedestrian interpretations. Using the Australian curriculum principles, Keirl explores the strategies for critiquing for different age phases and a range of possible classroom-based work that could be used to help children become more experienced in developing these deeper ways of thinking. This is a supporting chapter for those departments looking to rejuvenate their curriculum content and deepen the design and technology learning experience.

Chapter 11: Health and Safety in Design and Technology by David Leask

Leask starts with why health and safety is important and why trainee teachers need to be accompanied in the rooms with potentially hazardous tools and equipment. This is a good starting point for design and technology trainee teachers as the language is easy to access and getting the basics before starting school placements. Eventually trainee teachers will have to access original health and safety documents and generate their own risk assessments and reading this chapter will ease that path. The chapter also outlines the responsibility of the teacher and the employer. There are some helpful hints and tips on managing safety and a useful checklist for the design and technology classroom. Advice on Control of Substances Hazardous to Health (COSHH) and being familiar with those that you use are explained. Carrying out risk assessments and managing any hazards as well as what to do if you have an accident is also explored. There is some guidance on the different areas of teaching in design and technology. Leask ends with a caution that you need to read more widely than just this chapter to be fully conversant with health and safety.

Part 3: Teaching Design and Technology

Part three covers the teaching of the subject. In looking at the break down here, this part highlights the many elements to planning, teaching, and learning and the paperwork associated with each element.

Chapter 12: Planning Lessons in Design and Technology by Sarah Davies

The lesson planning chapter provides a generic approach to short term planning that covers the main elements of a typical lesson. This is a useful starting point for lesson planning for trainee teachers. Davies has given a clear indication of what a good lesson plan would contain. The distinct phases during the lesson are outlined as well as using Blooms Taxonomy in planning and preparing sources to present rich learning. Reading this chapter gives the underpinning to why planning at this level can help trainee teachers understand the number of activities that the teacher manages in a good lesson. There is also the separate phases of the lesson and transition within lessons that need to be carefully thought out. It also helps to reflect on lessons that are unsuccessful and learning to be prepared. The follow up sources are excellent.

Chapter 13: Key Pedagogies in Design and Technology by Matt McLain

McLain starts with a brief historical overview of the subject history and the pedagogies that came with that rationale for the subject. He covers a range of approaches, activities, and key processes, and explains the unique nature of teaching and learning in design and technology. There are details on skills, knowledge and understanding gained through group work, teamwork, and individual work, giving some interesting insights to reflect on and use when planning the design and technology curriculum. He explores teacher demonstrations, revealing some limitations and challenges in this way of working and leaves you with something to consider when it comes to choosing how to teach a lesson. This is a useful chapter to think about and understand how you organise learning when teaching design and technology .

Chapter 14: Planning for Progression in Design and Technology by Alison Hardy

Hardy starts the chapter with design and technology capability and what this is in terms of knowing and utilising that knowledge in application to design and technology classwork. She then goes on to different formats for planning the design and technology curriculum. Hardy explains how this involves the exploration of long-, medium- and short-term planning where progression of that knowledge can be arranged to be delivered in phases. There are some particularly good examples for curriculum planning. Trainee teachers begin to learn about planning with short term plan, i.e., a lesson plan; and then work their way up to understanding long term planning. However, this is not an easy path and this chapter is particularly helpful in gaining an understanding of why planning, learning to plan for the long term and planning for progression are key to teaching good design and technology. The follow up reading is good.

Chapter 15: Assessing Design and Technology by Suzanne Norris

Norris explains the primary areas of assessment and assessing and why we need to these. The chapter is easy to navigate, and the definition of the most commonly used assessment methods are clearly explained. The chapter gives the underpinning theories for using assessment in the classroom. There are some great strategies that could be integrated in any design and technology lesson. Some key design and technology literature to follow up is included here. For trainee teachers this chapter uses accessible language to gain a good understanding of the concepts that underpin good assessment in school and one to read before starting to assess any work.

Chapter 16: Developing Links with Other Subjects by Deborah Winn

Winn outlines the different curriculum subjects and gives an overview of some of the potential connections that could be possibly made. This chapter is a starting point and there are more ways of creating cross curricular work with other subject departments.

Part four: Developing your design and technology Career

Part 4 starts with values in design and technology and this chapter questions the role of technology in society and how design and technology can generate a deeper understanding of the aspects that are problematic about technology and technologies in the world. There is much here about the greater impact of the subject in the society and our understanding of that impact.

Chapter 17: Values in Design and Technology by Mike Martin

Martin philosophises about values and makes some particularly good pointers to how this could be integrated into everyday design and technology activities to enhance children's learning and knowing. He starts by unpicking the terms technology and technologies. How these are part of everyday life that go unnoticed. How these are used to judge countries, peoples, and cultures. Martin elucidates how technologies shape society, values, and principles. He touches on the impact both positive and negative and using examples to show how children can be taught to notice, to think and to understand the bigger picture. Martin explores ways in which to inspire children to develop skills to recognise values in everyday things.

Chapter 18: Transitions after Secondary Design and Technology by Rebecca Topps

This chapter would be useful for all secondary design and technology teachers. Topps presents a comprehensive list of the qualifications that can be chosen after studying in secondary school. Looking at the post-16 options available confirms how generic design and technology education is in the secondary classroom. There are various routes available and once in the post-16 territory, students would need to know what they would want to specialise in to select the course of study. It is this specialising that would be helpful for secondary teachers to be able to guide their students to the appropriate routes. Knowledge of these qualification will influence curriculum planning particular in the later stages of study and can also inform events like open evenings, parent evenings, developing a rational for the subject, etc. Having this knowledge and using it to promote key stage 4 would likely improve the numbers choosing the subject.

Chapter 19: Your Professional Development by Liam Anderson

Anderson eloquently presents the professional development from a trainee teacher to a fully accomplished classroom teacher. This chapter gives a comprehensive progression from reading an advert for a teaching post, interpreting it, writing letters of application, application forms and the process of a teaching interview. It also gives the trainee teacher tools to look for the correct school setting and planning for a career in teaching with professional development and preparation for advancement. Every trainee teacher needs to read this chapter.

Chapter 20: Using and Producing Design and Technology Education Research by Stephanie Atkinson

Atkinson rationalises how classroom practice continually evolves and how the nature of design and technology is a subject that is also continually evolving. She uses the work of teacher researchers as well as academic researchers as sources to support the benefits of practitioner researcher – classroom teachers have direct access to experiences that need sharing not only with the design and technology community but also with the world to establish more strongly the notable place of design and technology education in the national curriculum and why it should not be side-lined. Atkinson explains how you can get started on your own practitioner research. This chapter would be helpful for all trainee teachers, teachers, teacher researchers and for those tat the beginning of master's level study.

To conclude, this book is a good support for those training to teaching design and technology. It gives new teachers the underpinning history and ways of working and thinking about design and technology. It is a reliable source for gaining insight into good practice and ways in which the subject content in schools can be generated creatively.

References

DfE, 2014. *National curriculum in England: framework for key stages 1 to 4 - GOV.UK*. [online] Gov.uk. Available at: <https://www.gov.uk/government/publications/national-curriculum-in-england-framework-for-key-stages-1-to-4/the-national-curriculum-in-england-framework-for-key-stages-1-to-4>