24.2

Design and Technology Education: An International Journal

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Guest Editorial - Cultivating emerging research agendas from the PATT community

Donal Canty, Technology Education Research Group (TERG), University of Limerick, Ireland

Niall Seery, Technology Education Research Group (TERG), Athlone Institute of Technology, Ireland

This special section is comprised of submissions that originated at the 2018 Pupils Attitudes Towards Technology (PATT) conference and supports the further articulation of thinking and research that was presented at the event.

For us, the PATT 36 conference in Athlone, Ireland was a significant milestone for the Technology Education Research Group (TERG). It was a point of reflection that allowed us to recognise the culmination of our endeavours and the level of development since our inception in 2010. It allowed our emerging talent (specifically PhD students) shape the focus of the conference and helped define a clear rationale for their own research agendas and how it supplements, challenges, or re-orientates the contributions and evidence to date. For TERG, being part of the PATT community is strategically important as it provides support for dissemination, networking, critique, and advice, but more importantly the PATT 'family' is about recognising and developing people with a shared interest in developing technology education. TERG emerged through an agenda of building a research culture and developing expertise and is underpinned by a philosophy best captured by the old Irish proverb, "Mol an óige agus tiocfaidh sí" - praise the young and they will flourish. It is this sentiment that sustains PATT endeavours!

PATT36 has had an immeasurable impact on the TERG members and for that we are very grateful.

The theme of the conference, *Research and Practice in Technology Education: Perspectives on Human Capacity and Development*, evolved from previous conferences and research produced by the community over a period of time and focused on the utility of research in enhancing practice. This focus framed an overarching agenda that attempted to capture the fullness of human capacity while maintaining a commitment to supporting personal development. Sub-themes were conceived to capture the essence of the role and importance of technology education and authors were invited to present works that focused on the following themes:

- Cultivating Imagination and Innovation
- Learning through Design and Make
- Driving Social Change

We invited interested stakeholders to attend the conference and access the conference proceedings to give visibility to the comprehensive contributions and developments in technology education made at this conference. The following section outlines a number of papers that represent a 'snapshot' of the contributions.

The selected papers from PATT36 were chosen to demonstrate the breadth and relationships between research agendas, which remains the core strength of the PATT community. The contributions frame a sample of the research enquiry and take us through a journey from the very definition of design and technology education, its manifestations, and how various interpretations still resulted in similar issues and challenges. They also present how our response as researchers has helped evolve contemporary research agendas. The following papers have contributed to the conference theme of Research and Practice in Technology Education: Perspectives on Human Capacity and Development.

We begin with interesting work in the UK, authored by Matt McLain, Dawne Irving-Bell, David Wooff and David Morrison-Love. The paper entitled *'Humanising the design and technology curriculum: why technology education makes us human'*, helps set the scene for defining the nature of technology education. This paper explores the origin and theoretical underpinnings of Design and Technology (D&T) and advances the discourse on the potential and function of D&T education. The paper sets the baseline of an evolving research agenda that will help shape at a fundamental level how we describe design and technology education in the future. Although the context for the paper is in the UK framing of the subject, it has implications for the international discourse as we all endeavour to advocate for technological education. The systemic and political tensions are referenced and should be considered subject to the fundamental positioning of D&T. The importance of the cultural and historical perspectives are emphasised and a position taken to reframe the relationship with technology and society. This by virtue promotes D&T as fundamentally human.

The concept of a humanising experience that is culturally sensitive, brings with it one of the most significant challenges in technology education. The variance in participation rates by gender is a complex and long standing research agenda for the PATT community. This challenge is tackled by researchers in Sweden with their paper *'Girls' engagement with technology education: A scoping review of the literature'.* This research agenda focuses on access to technology education while emphasising how perceptions are impacting access.

Ulrika Sultan, Cecilia Axell and Jonas Hallström present the findings from their scoping literature review, highlighting the research agenda, methodological approach, and the critical issues relevant to girls' engagement with technology. Worryingly, the majority of studies report that girls are more reluctant to participate in technology, science and/or STEM fields, less interested in the subject and more negative towards technology (education) than boys. The gender difference is framed and discussed in the paper and highlights the societal and cultural influences that contribute to the origin and possible sustained variance defined by the expectations and definition of male and female roles. Importantly, this paper questions the nature of the technological activity and the relationship between girls and tasks and activities that are relevant to the development of technological literacy and capability. This reference of 'near to practice' research will certainly ensure new insights but also enable us to consider the cultural and societal factors that may amplify or filter the agenda of ensuring the fundamentally human orientation of D&T.

It is arguable that much of the legacy perspective or interpretation of technology subjects originates from the vocational intention. In many countries this resulted in a curricular articulation of the elements of technology education. Typically, *Textiles and Food, electronics* and *resistant materials* were separated by a historic and vocational agenda that reinforced perceived gender orientations. The work of researchers in Finland, Juha Jaatinen and Eila Lindfors titled *'Makerspaces for Pedagogical Innovation Processes: How Finnish Comprehensive Schools Create Space for Makers'*, has focused, not on the issue of gender, but the significance of the learning activity and learning environment. Sensitive to the cultural importance of craft education, this research elaborates on the importance of the maker space in the context of a contemporary learning agenda. The importance of the contribution is in highlighting the move from an emphasis on production in a maker spaces towards more meaning-making in the application of knowledge and skills. This work takes a contemporary look at craft skills and the importance of the relationship between designing and making in the acquisition and development of innovation. This focus on activity again frames a useful research agenda that has the potential in the future to contribute to the fundamental understanding of the importance of design and technology activity.

The strength of the PATT community is support for the evolution of thinking. This has resulted in the iterative visiting of core issues in design and technology, but also evolutions and synergies in the way researchers are redefining the research effort. The importance of building on sound empirical evidence both within and beyond D&T supports a useful agility in emerging research and researchers. The paper titled *'Children's Responses to Divergent and Convergent Design Feedback'* by Alice Schut, Remke Klapwijk, Mathieu Gielen and Marc de Vries builds on the evidence of feedback as a critical dimension of contemporary provision and highlights its importance in the context of design activity. This agenda further developed the classification of divergent and convergent feedback as it applied to the objective of moving the learning forward. The insight that has developed from the basic enquiry is framed from the perspective of pedagogical practice with an emphasis on how we must think about how our actions as teachers may impact on learners. The need for all involved in the educational transaction to become more skilled in giving and receiving feedback and the need for more openness in relation to feedback conversations is presented.

It is hoped that this special section captures in some way the significance of the PATT community to the advocacy of design and technology education and highlights the emerging research agendas and talent that is supported in this community. It is also hoped that it encourages and informs researchers, teachers and other stakeholders that engage with PATT at an exciting time for our community.

It was a privilege for us to edit this special section and we would like to thank the PATT community for making PATT36 (and all PATT conferences) a very special memory for us. We would like to thank the authors for their contributions and ensuring that the future of PATT remains bright. And finally, a sincere thank you to Professor Kay Stables for her guidance and expertise as we developed this special section.

Humanising the design and technology curriculum: why technology education makes us human

Matt McLain, Liverpool John Moores University, England, UK

Dawne Irving-Bell, Edge Hill University, England, UK

David Wooff, University of Sunderland, England, UK

David Morrison-Love, University of Glasgow, Scotland, UK

Introduction

Design and technology (D&T) emerged from a very different education context than it finds itself in today. D&T was to be included in the National Curriculum for England because it was perceived that what children learnt from design and technological activity could not be learnt in another way (DES/WO, 1988). Furthermore, it connected a wide range of subjects across the curriculum, developing capability "to operate effectively and creatively in the made world" (p.3). Henceforth, the role of knowledge for action in D&T, primarily through designing and making, has been viewed as a great strength and unique feature in the subject (cf. Black & Harrison, 1985; Kimbell, 2018; Kimbell, Green, & Stables, 1996; McCormick, 1997; Morrison-Love, 2017).

D&T emerged into the curriculum, in England, from craft education roots (Allsop & Woolnough, 1990) to its more modern, design oriented, iteration (Atkinson, 1990). It has been a somewhat challenging journey from the outset, with calls for agreement on its purpose, nature and value in the curriculum (Wright, 2008). However, in the face of a paradigm shift, from the teaching of individual material-oriented and traditionally gendered subjects (home economics and craft design and technology) to a unified design-oriented curriculum, many teachers retreated into familiar territory (McLain, 2012; Paechter, 1995) – i.e. craft and material based skills and practice. The focus on capability under the multidisciplinary umbrella of D&T, whilst compelling within the D&T education community, has arguably failed to win the hearts and minds of many. Indeed, the relative lack of the subject's own body of propositional knowledge has recently led to criticism under the influence of a so-called knowledge rich curricular ideology (DfE, 2011, 2016; Gibb, 2017). D&T has also been criticised for failing to live up to its early expectations in many schools, struggling with the constraints of a content focused curriculum and assessment (McGimpsey, 2011; Miller, 2011) and a lack of "funded and systematic research" (Harris & Wilson, 2003, p. 62).

The aim of this paper is to reposition and reinvigorate how D&T is interpreted and enacted within the school curriculum. Not merely as an industrial imperative, with its focus on technical and economic matters, but on D&T as a cultural, creative and humanising endeavour. Our argument is that technological activity is fundamentally human and integral to our evolution and development as cognisant and social beings. Therefore, to measure a subject by it's so called timeless knowledge in opposition to skill (Gibb, 2016) falls short of achieving a broad and balanced curriculum (Spielman, 2018); in particular a relatively new and evolving subject encompassing the complexity of technology and society, with their complex and changing natures. However, there may be light at the end of the tunnel, with inspection findings of "evidence of curriculum narrowing" in England and the negative impact of focusing on "few measurable outcomes" (Ofsted, 2019, p. 5); which may result in a resurgence of opportunities for pupils to study practical and creative subjects, such as D&T, in opposition to the perverse incentives that have led to said narrowing in school curricula.

Theoretical Framework

Curriculum can be viewed and understood through different theoretical lenses, each with their own drivers, such as aims (Reiss & White, 2013), knowledge (Young, 2008) and experience (Biesta, 2014). In these politically turbulent times for D&T in England, we adopt a pragmatic stance (Biesta, 2014; Biesta & Burbules, 2003; Dewey, 1966, 1944, 1916) side stepping the whole knowledge verses skills debate and focusing on experience and the interaction between mind and hand (Kimbell et al., 1996). We do not argue for a new curricular hegemony, dethroning knowledge and reinstating skill, but a more nuanced and accommodating political climate with regard to curriculum and pedagogy – both the 'Big P' of national and the 'small p' of local policy and practice.

Figure 1. Evidence of technology in the natural landscape (McLain, 2018)

With regard to technology, we consider it as inextricably linked with society and social activity, evident within even the most natural seeming historic landscapes Figure 1 the marks of land management (dry stone walls) and urban infrastructure (reservoir); not to mention paths and other signs of human action and interaction with our environment endure. Rather like a Mobius strip, Figure 2 with its surfaces intertwined in a dynamic interaction, as a visual metaphor for socio-technological human activity. Denying absolute or dualistic interpretation of the world (Russell, 1993), in the traditions of pragmatism, technology and society are viewed holistically as part of a "technical-social way of life" (Bruner, 2009, p. 160).

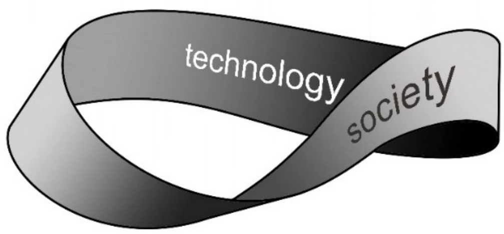

Figure 2. Mobius representation of technology and society (McLain, Irving-Bell, Wooff, & Morrison-Love, 2018, 2019)

As indicated above there are several challenges facing D&T, as a curricular entity, namely its unique body of knowledge and the multiplicity of meanings of technology. With the aim of exploring D&T experience at the present time, some problem finding (Chand & Runco, 1993) may help bring into focus some of the unspoken complexities or assumed shared understanding around knowledge and technology. To this end we will briefly explore Mitcham's modes of the manifestation of technology (Mitcham, 1994) and Bernstein's classification and framing (Bernstein, 1971).

The problem with D&T

The current United Kingdom government began its educational policy reform with an expert panel report concluding that some subjects, D&T, information and communication technology (ICT) and citizenship, had insufficient "disciplinary coherence" (DfE, 2011, p. 24) compared to other subjects. As a result, computing (computer science) rose, like a phoenix, from the ashes of ICT and both D&T and citizenship were proposed to be reclassified. The footnote for this judgement justified the panel's stance as taking "a view of disciplinary knowledge as a distinct way of investigating, knowing and making sense with particular foci, procedures and theories, reflecting both cumulative understanding and powerful ways of engaging with the future"(p. 24). This is a dense phrase, so let us pick at the thread in an attempt to understand. Firstly, the authors did not appear to believe that D&T had distinct disciplinary knowledge. Second, that they did not believe that D&T had a distinct disciplinary approach; pedagogy, if you will.

Viewed as an educational construct (Bell, Wooff, McLain, & Morrison-Love, 2017) D&T lacks a distinct body of knowledge when its component parts are analysed (Figure 3). Bell et al. (2017) examined common disciplinary areas in the subject as hard/soft and applied/pure. Perhaps not unexpected, the knowledge 'territories' occupied the applied side of the curriculum, but tensions between so called *hard* and *soft* knowledge were evident. This tension is evident within individual disciplinary areas, such as textiles, where 'technological' textiles and 'apparel' textiles are located in opposing quadrants in the hard/soft continuum. So-called *hard* subjects being more concerned with adherence to a relatively definable body of knowledge (didactics), and *soft* to the process of acquiring and creating knowledge (pedagogics). This fluidity, combined with the shifting nature of technology and society, makes D&T difficult to define and contain. What could be viewed as a strength, i.e. the ability of a subject to evolve over time to equip children and young people for life in an evolving society, becomes an impediment where knowledge is required to be organised and timeless.

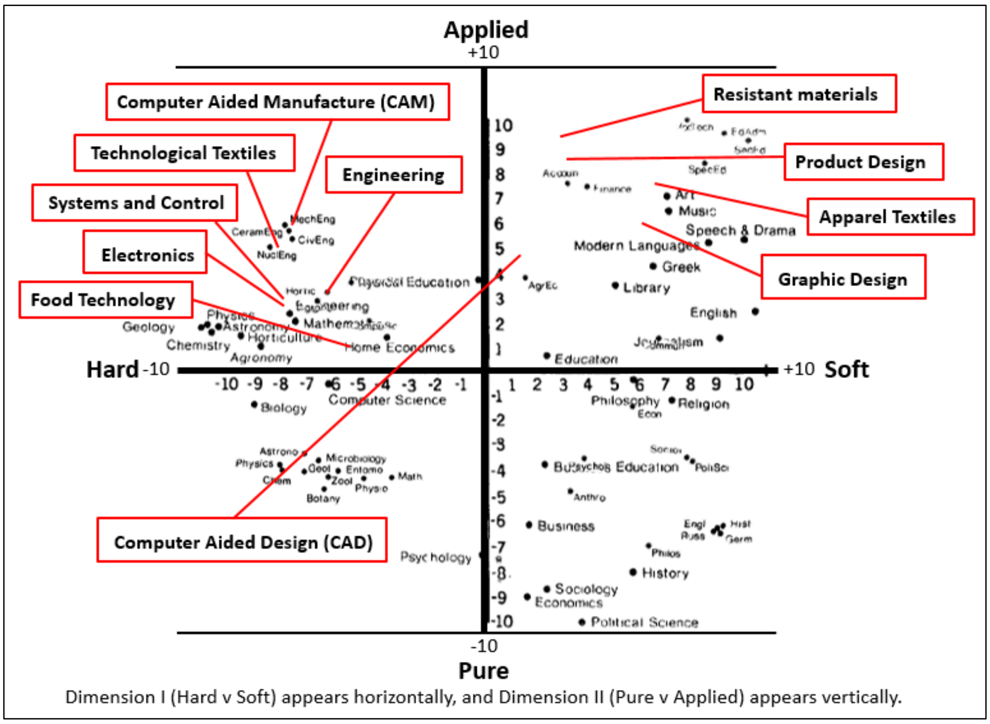

Figure 3. Knowledge territories within design and technology (Bell, 2015; Bell et al., 2017)

At this point the typical D&T educator waves their hands in the air and says, "but hold on…!", little realising that there is possibly an unspoken bias or agenda. However, the expert panel's repeated choice of "powerful" and "powerful knowledge" on six occasions (2011) indicated a bias towards Young's analysis of knowledge and power (Muller & Young, 2019; Young, 1971, 2008), where certain specialised, context-independent knowledge is considered valuable on the grounds that it provides the basis for making generalisations and claims. This perspective considers the aforementioned kinds of knowledge to be more important, or valued, than 'mere' procedural and context-dependent knowledge that add depth and breadth to D&T and other practical and creative subjects. Similarly, the term 'cumulative' implies a hierarchical knowledge structure, where one concept builds on another, which is not the case for all subjects; some of whom have a more 'segmented' or horizontal (non-hierarchical) knowledge structure, where there is no predetermined or ideal sequence of learning (Maton, 2009). Both cumulative and segmented learning have their merits and problems, and the strength of the later (of which much encompasses D&T learning) is contextualised learning, which is also criticised for potentially inhibiting transfer and generalisation of knowledge.

The panel go on to give this trio of 'could do better' subjects (D&T, ICT and citizenship) a somewhat backhanded compliment about the worthwhile nature of such applied learning, albeit with "weaker epistemological roots". Therefore, we might ask how we find ourselves in this conundrum and whether it is a surprise, given the nature of D&T disciplines and their associated knowledge. We contend that, in some subjects and in a "technologically advanced society" (Ofsted, 2011, p. 4), change might be viewed as a good thing. Similarly, the somewhat segmented nature of some D&T learning, which extends into a range of knowledge associated with other disciplines, and focuses on designing and making in a variety of contexts, should be view as an essential part of the subject's *raison d'être*, rather than a 'weakness'. For example, the purpose of study statement, in the National Curriculum programme of study (DfE, 2013, p. 234), states:

> "…Using creativity and imagination, pupils design and make products that *solve real and relevant problems within a variety of contexts, considering their own and others' needs, wants and values***.** They *acquire a broad range of subject knowledge* and *draw on disciplines such as mathematics, science, engineering, computing and art*... Through the evaluation of past and present design and technology, *they develop a critical understanding of its impact on daily life and the wider world*. High-quality design and technology education makes an essential contribution to the *creativity, culture, wealth and well-being of the nation*." [*emphasis ours*]

From the earliest times in human history, we have used tools to shape our physical and social environment. It has been suggested that Homo Sapiens (the wise or thinking man) could have easily have been Homo Faber (the working or making man). Arendt placed the notion of human activity firmly with in the social ("world of men") and the technological ("man-made things") environment (1998, p. 22). This is the world into which we are born and together, inseparable, "form the environment for each of man's [sic] activities" (p. 22). Arendt traces a contempt for labour rooted in the origins of western thought, which continues to this day, fossilised in Aristotle's classification of Epistēmē (scientific knowledge) and Technē (craft knowledge) (Scharff & Dusek, 2003), with the latter being somewhat undervalued and understudied, in a systematic way (Hickman, 2001). This, despite emerging evidence from modern science as to the importance of technology and tool use in human evolution and cultural development, including the heuristic approaches to problem solving leading to causal beliefs (McCormack, Hoerl, & Butterfill, 2011; Wolpert, 2003) or language (Campbell, 2011; Greenfield, 1991).

Therefore, technology sits in relative epistemic obscurity, compounded by a plethora of definitions and perspectives which Mitcham attempted to draw together into a "set of quasi-empirical categories" (1994, p. 269). Mitcham noted the tensions between the scientific abstraction and technological application of knowledge, identifying four modes (categories) in which technology manifests itself in society: technology as object, as knowledge, as activity and as volition (Figure 4).

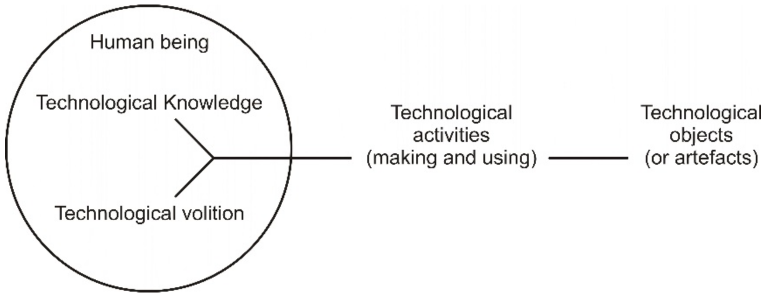

Figure 4. Mitcham's Modes of the manifestation of technology (Mitcham, 1994, p. 160)

Mitcham further classifies technological knowledge and volition as being concerned with human ‘being’, with making and using of technology being external activities resulting in technological objects, which in D&T would be referred to as products or prototypes. The link between the *object* and activity modes are familiar features of the D&T curriculum, with a focus on designing, making and evaluating prototypes (e.g. products or systems). As stated above, knowledge becomes problematic in the current political climate. However, Mitcham defines technological knowledge with taxonomy developing from heuristic approaches of mimicry and trial and error (sensorimotor skills), to rules of thumb (technical maxims), recognised causal effects (descriptive laws) and real world application of theory (technological theories). Technological theories begin to develop cumulative (hierarchical) knowledge, and are part of D&T. For example, the “functions of mechanical devices” or “categorisation of the types and properties of… materials” (DfE, 2015, p. 6) . However, this is alongside the more heuristic aspects requiring an understanding “that all design and technological practice takes place within contexts” and of “client and user needs” when designing and developing ideas (p. 7). Considered through Mitcham’s mode of technological knowledge, the D&T curriculum includes a rich variety of learning across the spectrum. The fourth mode, volition, describes the human drive for control and freedom, which affects human beings’ thinking, values and motivation. In this mode, Mitcham emphasises technology’s role in the practical and incremental developments “embodied in culture and perpetrated by tradition” (Mitcham, 1994, pp. 36-37). This technological volition is a fundamental human drive, compelling activity and objects with evolving knowledge from prehistoric times. Rather than technology being viewed as a hard or rigid field, in the context of D&T we propose that it humanises the curriculum; recognising the cultural importance not just of what ‘we’ produce, but how and why we do so.

Having focused on the wider understandings of technology in society, the notion of the ‘subject’ or discipline in education provides a further insight into the problem of D&T. Bernstein, in an attempt to understand why lower socioeconomic status children do less well in school, analysed language to distinguish between school (elaborate) and everyday (restricted) language in order to understand how children learn (Bernstein, 1990). He concluded that children’s understanding of the language used in school subjects may either enable or inhibit their access, and thus their ability to articulate their thoughts. This poses a two-fold problem to a subject like D&T, the first of which being the aforementioned complexity and ambiguity of technology in society and the second the technical nature of the language often employed.

Furthermore, Bernstein (1971) *classified* subjects according to the relationships between what knowledge is taught by different subjects (curriculum), and *framed* by how subjects are learnt (pedagogy). This classification and framing of subjects led to the identification of so-called boundaries between subjects, where subjects with unique and definable knowledge where classified as 'strong'. In contrast, subjects that share knowledge or adopted thematic approaches to teaching were classified as 'weak'. In the National Curriculum, D&T has been presented as drawing on knowledge from other subjects (DfE, 2013, 2015); a feature that when viewed through Bernstein's classification and framing, and a focus on powerful knowledge (Young, 2008), appears to undermine its purpose in the curriculum. As discussed above, D&T knowledge does not reside comfortably in a single domain (Figure 3) and leads to perceptions that it lacks a solid knowledge base; cementing the argument that, the knowledge base for D&T is 'weak', which under the lens of this analysis appears as an amalgam of so-called 'hard' (hierarchical) and 'soft' (segmented) learning.

Therefore, knowledge seems to be at the heart of the problem with D&T; or perhaps more accurately the current interpretation of knowledge by the policymakers in England at this point in time is a problem for the D&T community to address. We suggest that the answer is not a list of declarative or propositional knowledge, as important as these are, but a meaningful debate with policymakers about the nature of curriculum and the value of different kinds of learning – and thus knowledge. We return to a broad and balanced curriculum, not being bound by an ideological interpretation of knowledge, but recognising complexity and the multiple realities of human beings' experiences of technology and society.

A solution for D&T

Mitcham's perspective on technology illustrated the complexity and multi facets that affect how society understands the term; and prompts us to be clear about whether a D&T curriculum should be dominated by knowledge, objects, activity or volition. As we have seen from Bernstein's classification and framing, knowledge it somewhat problematic for subjects that draw in other disciplines, or where knowledge evolves over time. Also, an over emphasis on technological objects, such as prototypes that pupils design and make (important as these are) may be somewhat limiting. A reframing of the argument for D&T should acknowledge the importance of technological activity (including problem solving and design thinking) and volition in human development. In other words, D&T has a potentially humanising role to play in the curriculum, at odds with the oft-bleak portrayal of technology through dystopian or deterministic lenses.

> "When education, under the influence of a scholastic conception of knowledge which ignores everything but scientifically formulated facts and truths, fails to recognize that primary or initial subject matter always exists as matter of an active doing, involving the

use of the body and the handling of material, the subject matter of instruction is isolated from the needs and purposes of the learner, and so becomes just a something to be memorized and reproduced upon demand. Recognition of the natural course of development, on the contrary, always sets out with situations which involve learning by doing." (Dewey, 1966, 1944, 1916, p. 217)

A pragmatic view of education (Biesta, 2014; Biesta & Burbules, 2003; Dewey, 1966, 1944, 1916) eschews the pendulum swing from knowledge to skills (e.g. Gibb, 2017), and vice versa. Pragmatists, such as Dewey, challenge the learning of facts that is devoid of application, favouring approaches to curriculum and pedagogy that accommodate knowledge 'and' skill, rather than privileging one over the other. In the above quote from Dewey's seminal work on democracy and education, the somewhat convoluted message is to broaden our notion of knowing to include "active doing"; to balance knowing that (conceptual knowledge) with knowing how (procedural knowledge) (McCormick, 1997; Ryle, 2000, 1990, 1963, 1949). From a pragmatic perspective, the problem of knowledge in D&T retreats, like an optical illusion rotating to reveal a hidden image. We return to D&T capability (Black & Harrison, 1985) and the interaction between mind and hand (Kimbell et al., 1996). So a solution may be to think differently, more pragmatically, about the design and technology curriculum.

In order to do this, we must first and foremost understand the underlying assumptions underpinning educational reform. In the current situation, knowledge is in the ascendency over skill, in the mind of the politician (embodied in the secretary of state for schools). The pragmatic side step is to avoid the difficult to define knowledge and focus on experience, but that will not quite do when programmes of study focus on timeless concepts. So the question focuses on the nature of knowledge in D&T and to what extent it is different or unique (strong). As we have discussed, much 'uniquely' D&T knowledge is contextual and by its very nature might be labelled as 'weak' or segmented, and this is fundamental to the intentions for the subject from its origins (DES/WO, 1988) to the present day (DfE, 2013, 2015). Therefore, to constrain the D&T curriculum to a framework informed by so called knowledge rich or knowledge led philosophies (Gibb, 2016, 2017; Young, 1971, 2008) is likely to be an ultimately futile activity with the subject being forever classified as 'weak' (Bell et al., 2017; Bernstein, 1971; McLain et al., 2018).

We propose a reframing of the discussion of knowledge in D&T, and beyond, to pragmatically focus on the curriculum as experience (Biesta, 2014; Biesta & Burbules, 2003) and remove the artificial distinction between knowledge and skill. It should instead, focus on and value both knowing that something is the case (conceptual) and knowing how to do or act (procedural) (Ryle, 2000, 1990, 1963, 1949). Conceptual and procedural knowledge in a symbiotic, non-dualistic, relationship with thinking (head) and action (hand) working together – knowledge for action (Kimbell, 2018; Kimbell et al., 1996) with 'transformation' - of resources into objects to shape our environment - at the heart of our pedagogy and curriculum (Morrison-Love, 2017).

Conclusions

We contend that D&T is culturally important, as technological knowledge, volition, activity and objects play a central role in human and societal development. In a changing technological landscape, surely a technological curriculum must also be free from constrain, allowed to change – to evolve – without a requirement to align with certain ideological theories. The prevailing views on knowledge and curriculum amongst policy makers present an apparently impenetrable and unmoveable hegemony (as narrated in relation to recent education policy in England), which fails to recognise the complexity of 'technology' and expects all subjects to define themselves by a body of universal and timeless concepts. We say this is simply not good enough for our children who deserve a broad, balanced and rich curriculum, rather than narrowing choice. We call for policy makers to listen to and understand subject communicates and refrain from imposing unsuitable and ideologically influenced frameworks - one-size-fits-all is not fit for purpose.

We encourage D&T educators (teachers, teacher educators, leaders and researchers alike) to engage with the debate on knowledge, curriculum and pedagogy and to be aware of and to understand the implications and impact of political and philosophical ideologies on educational reforms, including how these are enacted in the school curriculum. It is particularly important for D&T teachers and the wider community to understand the nature and role of knowledge in the subject. An agenda for D&T stakeholders, curriculum designers and educational researchers should promote D&T as fundamentally human and humanising experience, with a cultural role to play where knowledge for action is central, in context and with a purpose.

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Girls' engagement with technology education: A scoping review of the literature

Ulrika Sultan, Linköping University, Sweden

Cecilia Axell, Linköping University, Sweden

Jonas Hallström, Linköping University, Sweden

Abstract

The aim of this study is to review internationally published scientific literature on the subject of girls' engagement in technology education, in order to identify the most common descriptions of girls' engagement with technology education, girls' technological activities, and the relationship between girls and technology. After a scoping review of the literature, 20 relevant articles were identified and included in the study; they were analysed using content analysis. The results show that, according to the reviewed studies, girls are less interested in and have less positive attitudes towards technology (education) than boys. They are also less likely to choose a technology- or STEM-oriented occupation. Several of the included studies venture possible explanations as to why this is and refer mainly to cultural factors. Those studies that do define the type of technology used in girls' activities mostly describe a neutral, or male kind of "nuts and bolts" technology. As regards girls' relationship to technology, there is potential for improving female engagement using apparently simple means; for example, making sure the social context of teaching is adapted to girls. The results of the literature review are discussed in terms of their implications for future research and can be used as a guide for educators and researchers in the area. In particular, the reasons for girls' lower interest in technology education compared to boys need to be further researched, and it may be that researchers need to study girls in their own right, not in perpetual comparison with boys, in order to come closer to an answer.

Keywords

girls' engagement, gender, technology, technology education, scoping review

Introduction

That there is a relationship between gender and technology, manifesting in structures, symbols and identities, has long been acknowledged by feminist scholars. However, the feminine connection with technology has been downplayed in public discourse, in favour of the male connection. Feminist scholars of technology (e.g. Harding, 1986; Cockburn & Ormrod, 1993) argue that everyday discourses of technology constitute a prominent factor causing negative stereotyping and gender norms. These norms fuel ideas of what technological agency is, as well as whose interest in technology and what kind of technology are regarded as legitimate (Wajcman, 1991). There are therefore structures in society that influence girls' engagement with technology and technology education from an early age. Indeed, the fundamental concept of technology, which is generally coded as a male construct, may be problematic; technology is often constructed as a male domain composed of male attributes such as logic, structure and technical knowledge (Sanders, 2005).

Why so few girls pursue a career in technology can be explained by such factors as lack of confidence, lack of support at home, in the classroom or from other authority figures, and lack of peer support, according to Cheryan, Ziegler, Montoya and Jiang (2017). Turja, Endepohls-Ulpe, and Chatoney (2009) argue that specific attitudes and roles hinder girls from engaging in technology education because technology is presented as an exclusively male domain. Cheryan et al. (2017) consequently claim that:

> even if the culture of a STEM field is not overtly hostile to women, women will be less likely to enter, persist, and be successful in a field when there is a mismatch between the way that they wish to be seen and are expected to behave and the norms of that culture. (Cheryan et al., 2017, p. 2)

Faulkner (2000) argues that stereotypes often relate to masculine instrumentalism and feminine expressiveness, with females being drawn into occupations that revolve around social interaction, and even, as Bredlöv (2017) points out, caring and “emotional labour”. De Vries (2006) concludes that girls are less confident than boys when handling so-called hard technology; computers, electronics and similar artefacts. This lack of confidence even extends to encounters with and use of what is identified as hard technology in schools (Kimbell, Stables, & Green, 1996). For example, girls are more likely than boys to feel confident about, and to succeed in, working with tables of data concerning health, reproduction, or domestic situations, but anticipate failure – “I don’t know anything about that” – when faced with tables of data on machinery, building sites, or cars (Murphy, 1990). Sadker and Sadker (1994) elaborate upon teaching methods by showing that teachers may inadvertently favour boys, especially in areas that society considers to be in the male domain, by providing them with more and better instruction.

This is problematic – the construal of technology and technology education as predominantly male domains – and highly relevant to the research field of technology education and needs to be addressed. There has been some research on gender and technology education from various perspectives; for example, in relation to early childhood education (e.g. Hallström, Elvstrand & Hellberg, 2015; Turja et al., 2009), Pupils’ Attitudes Towards Technology (PATT) studies (e.g. Ankiewicz, Van Rensburg, & Myburgh, 2001; Svenningsson, Hultén, & Hallström, 2018) and gender specifically (e.g. Klapwijk & Rommes, 2009; Virtanen, Räikkönen, & Ikonen, 2015). However, there is still a lack of research concerning girls’ engagement with technology and technology education. The aim of this study is therefore to review internationally published scientific literature about girls’ engagement with technology education in order to identify the most common descriptions of girls’ engagement with technology education, girls’ technological activities, and the relationship between girls and technology. Doing a scoping literature review of just these three elements is important given the still rudimentary scientific knowledge about how girls actually engage with technology in educational activities.

Methods for collecting and analysing data

A scoping literature review is a "type of review [that] provides a preliminary assessment of the potential size and scope of available research literature. It aims to identify the nature and extent of research evidence" (Grant & Booth, 2009, p. 101). This kind of review has similarities with a systematic review in attempting to be systematic and transparent, but is less systematised and rigorous because it aims to establish the extent of existing evidence and the requirements for further research (Grant & Booth, 2009). We therefore adhere to the step-by-step review scheme for systematic reviews devised by Kitchenham (2004), although we do not make the claims of a systematic review (Kitchenham, 2004). This scoping literature review focuses on international studies researching girls' engagement with technology education, and the method of data analysis employed is content analysis. Conventional content analysis is an inductive method, which means that it is probing and open-ended in relation to the aim and research questions and the scoping review format, exposing descriptions of girls' engagement with technology education, technological activities, and the relationship between girls and technology in the reviewed previous studies (Hsieh & Shannon, 2005). This also means that the results of the review are presented in quite a "raw" format in Table 1, and the analysis is presented under Summary of Results and Discussion.

To conduct this review, we followed a step-by-step guide for conducting reviews based on Kitchenham (2004), covering the following stages and activities:

Stage 1: Planning the review

- Activity 1.1: Identification of the need for a review
- Activity 1.2: Development of a review protocol

Stage 2: Conducting the review

- Activity 2.1: Identification of research
- Activity 2.2: Selection of primary studies
- Activity 2.3: Study quality assessment

Stage 3: Reporting the review

- Activity 3.1: Communicating the results

Planning and conducting the review (Stages 1 and 2)

Activities 1.1 and 1.2: Identification of the need for a review, and development of a review protocol

The identification of the need for a review (1.1) was accomplished in the introduction. The review protocol (1.2) is inductive and open-ended, as described above under method of data analysis. Thus, it basically follows the aim of the study and the broad areas related to girls' engagement including their; descriptions of girls' engagement with technology education, technological activities, and the relationship between girls and technology.

Activity 2.1: Identification of research

For the purposes of this study, data was collected in January 2018, in the prominent international online bibliographic database for educational research, ERIC (Education Resources Information Centre). Searches were limited to full texts in high-quality, international, peer-reviewed journals, written in English, and published between 1 January 2000 and 31 December 2017 (research over the last 18 years). The specific protocol executed in the ERIC database was: "Find all my search terms": girl AND interest AND technology AND education. The results of this data collection initially consisted of 117 articles.

Initially, the limitation "elementary" was included in the research. Applying this limitation resulted in only three articles. By excluding the word "elementary" from the search, we gained a wider scope of included articles and this resulted in a broader variety of technology education studies from several countries. Furthermore, elementary does not entirely match the ages 10–17 because they also overlap with secondary education. To be able to include the age span we wanted to examine, we therefore manually excluded all articles dealing with ages lying outside 10–17-year-olds. We wanted to look specifically at ages 10–17 because this is a stage of life that research (e.g. Sinnes & Løken, 2014) has identified as particularly formative for girls' engagement with technology education.

Activity 2.2: Selection of primary studies

The following inclusion criteria (IC) were used to determine which papers would be included in the review:

IC1: The article reports on research about girls' engagement with technology education; descriptions of girls' engagement with technology education, technological activities, and the relationship between girls and technology.

IC2: The article presents a discussion of girls' engagement with technology education; descriptions of girls' engagement with technology education, technological activities, and the relationship between girls and technology.

Articles were included only if both these criteria were met.

Five criteria for excluding (EC) articles were identified:

EC1: Afterschool activities. We wanted to examine technology education during the school day, in formal school technology education.

EC2: Science education. We wanted to look specifically at technology education studies, although studies on both areas were included as well as STEM (science, technology, engineering, mathematics) studies in cases where they came through in the search. The keywords "science" and "STEM" were thus not included in the searches, but might appear in the results if they turned up in the search and were found to be relevant in relation to the aim.

EC3: ICT Education or use of ICT tools and educational technology. This was excluded for being a tool for learning technology rather than the subject of technology specifically.

EC4: Computer science. This was excluded when handling the computer was the focus, and not technology *per se*.

EC5: Age span outside 10–17-year-olds.

The search thus generated 117 international peer-reviewed research papers. We analysed titles and abstracts regarding the inclusion (IC1–2) and exclusion (EC1–5) criteria, and 20 studies finally matched our full search criteria (IC1–2 and EC1–5) based on the research aim. These 20 studies were subsequently studied in full.

Activity 2.3: Study quality assessment

As observed in Table 1, 83% of the total number of research articles was excluded based on IC1–2 and EC1–5, finally resulting in 20 included studies. The quality of the studies was ensured by including only those published in international high-quality journals.

Results: Reporting the review (stage 3)

Activity 3.1: Communicating the results

Table 1 displays the results of the final sampling of the scoping review, in the order the studies came out in the search.

Table 1. Results of the final sampling

Article	Aim and/or research question(s)	Age span	Research design and main findings	Description of: 1. girls' engagement with technology education, and 2. girls' technological activities and the relationship between girls and technology.
Ardies, J., De Maeyer, S., & Gijbels, D. (2015).	Exploring the evolution of pupils' interest during the year(s) they attend mandatory technology classes, and determining the characteristics of differences between boys' and girls' attitude changes over time.	First and second grade of general secondary education	A longitudinal study with eight measurement occasions spread over the course of two years presented to capture the evolution of students' attitudes, making use of a multilevel growth model analysis. Findings show that students' interests and aspirations in the field of technology are not stable and do change during the first cycle of secondary education. The conclusion are if the goal of technology education at school is to promote 'a larger number of students in technological oriented studies and professions', there is still much to do.	1. When describing gender with regard to technology, girls are seen as being less interested, female students tend to have less ambition in technology and are underrepresented in the field. The researchers conclude in the literature review that, at age 10, interest in STEM does not differ between boys and girls and is rather high. From that age on, interest starts to decline, especially among girls. 2. "Females do not see themselves (yet) as technicians, as we found that in their perception about technology as a subject for both genders is rather low, which means that they think it is more something for male students only" (p. 381).
Ardies, J., De Maeyer, S., Gijbels, D., & van Keulen, H. (2015).	Research questions: What is the predictive power of students' characteristics regarding aspects of their attitudes towards technology? Is there a difference between boys and girls in first and second grade with respect to the evolution in attitudes towards technology?	Age 12–14	Questionnaire with multivariate multilevel analyses. "The results of the study showed a decline in interest in technology from the first to the second grade of secondary education. This finding appears to be stronger for girls. Interest in technology is significantly positively related to the amount of time that technology is taught for, as well as to the teacher. Parents have a positive influence on several aspects of attitude to technology when mothers and/or fathers have a profession related to technology." (pp. 43–44). The study does not confirm all stereotypical ideas concerning gender differences. Female students believe that they can study technology and have a technological career.	1. Girls are generally more negative towards technology as boys are found to be more positive than girls and with a less negative trend in the development of their attitudes. However, it is claimed that "these findings cannot be generalized without caution, since results differ from country to country" (p. 48). 2. Gender differences may correlate with the presence and the amount of actual play with construction toys.

Mammes, I. (2004).	The aim was to determine differences in the interests of girls and boys in technology and to support interest in technology more widely by technology education (p. 89).	Third grade	A quasi-experimental pre- and post-test design. The results showed that girls' and boys' interest in technological subjects can be developed. Furthermore, gender differences were reduced significantly by the teaching. Findings show that early exposure to technology education at school leads to a higher level of technological interest in both girls and boys (p. 98). Researcher concluded that "the low level of interest of girls is traceable to their socialisation, and more particularly to the fact that girls are not exposed as much as boys to technology" (p. 91).	1. "Women are clearly reluctant to participate in courses of studies for technology" (p. 89). A lack of interest results in a refusal to deal with technology and this leads to technological incompetence. 2. Activities that the girls took part in were a technology programme that consisted of a Christmas tree and components of the electrical circuit, and designing and making a nesting-box.
Autio, O., & Soobik, M. (2017).	Determine whether there is a relationship between students' undertakings within Craft and Technology education and their ability to understand technological concepts by asking three different research questions.	Ages 11 and 13	Quantitative survey. To evaluate students' technical understanding and reasoning, a questionnaire was devised, concerning mechanical systems based on physical principles. Then a numerical analysis was performed. One of the results is that the students did not perform as well as expected in the measurement of technical understanding and reasoning. Authors argue that practical skills can improve both technological knowledge and reasoning.	1. It is "not a surprise that boys and girls differ in their interests, the difference is usually emotionally charged" (p. 200) and a "possible reason for this might be the different social expectations for boys and girls" (p. 201). "Boys' and girls' different interests and earlier experiences obviously have an impact on motivation for learning about technology" (p. 193). "It is obvious that technological knowledge is important, especially in spatial reasoning; this has an impact on girls' motivation for learning about technology" (p. 201). 2. "Although, it was not the main goal of this research, we can't pass the differences between boys and girls. There were statistically significant differences between boys and girls" (p. 200). The girls were getting fewer correct answers in the questionnaire.

Andreucci, C. & Chatoney, M. (2017).	The aim is to shed light on the artefacts that are used to illustrate technology education textbooks. Study also provides answers to other questions: what are the technical artefacts in textbooks? How are these objects representative of girls' and boys' technology interests?	Ages 12–14	Conducted in two stages. Firstly, an inventory of artefacts presented in four technology education textbooks for the sixth grade was carried out. Secondly, this inventory was submitted to a population of 98 girls and boys to have them make a categorisation of these artefacts. The results indicated that "a majority of artefacts implicated are neutral, but those that are gendered are more masculine than feminine marked. This factor is likely to strengthen the girls' feeling that teaching of technology is more adapted for boys than for girls. It is therefore one of the possible barriers that contribute to the disaffection of the technology courses by girls" (p. 15).	1. Girls' lack of interest is seen as a social construction: "Furthermore, the social and cultural distribution of activities between men and women can also lead to a gendered vision of technical objects according to their predominant users" (p. 5). 2. The majority of gendered artefacts in the studied schoolbooks are stereotypically male, a factor likely to strengthen the girls' feeling that teaching of technology is more adapted for boys than for girls. "However, technological areas of women's interest are numerous: technologies related to health and its prevention, to meatpacking, to cosmetology, to dressmaking and accessories, etc." (p. 16). And these could be added to the curriculum.
Osagie, R. O., & Alutu, A. N. (2016).	The study investigated the factors affecting gender equity in science and technology among senior secondary school students. Research questions: What is the choice of subjects of senior secondary school students? What percentage of females/males choose science careers? What are the major factors that affect gender inequity in the choice of science and technology careers?	Average age 15	A case study survey administered to 150 students. Analysis revealed that sex, parental and peer influences, and social and cultural stereotyping were the major factors affecting gender inequity in the choice of careers in science and technology. The results showed that less than 40% of the girls indicated interest in science and technology subjects even though they had the ability. In comparison, more than 65% percent of the boys indicated interest in science and technology subjects, even though they were not academically prepared for them. It is concluded that girls should be introduced to science and technology subjects in a way that makes it clear that they could be successful studying them. There should be an improvement in student-teacher interactions to counter the stereotypical images of science that are still prevalent. Parents, teachers and other persons in touch with girls should be made aware of the important role they can play in girls' identity work and educational choice process with regards to science and technology careers (p. 235).	1. "People treat girls and boys differently from an early age, giving them different feedback and expectations. This study shows that there is strong evidence that the culture discourages girls from being interested in technology even when they demonstrate exceptional talent from pursuing science and technology careers" (p. 234). This has affected the type of education girls and women receive, even up to tertiary institutions. 2. 88.7% of female students indicated a lack of interest in science and technology. This might have its root in "self-doubt, stereotypes, discouragement, economics and sometimes just wrong perception of what math and science are all about" (p. 234).

Stevanovic, B. (2014).	The aim is to study the changes and constants in girls' choices in science and technology education.	Ages 11–18	Data based on surveys by the INSEE, France's National Institute of Statistics and Economic Studies, and DEPP, Directorate of Evaluation, Forecasting and Performance (p. 544) Results show that female enrolment numbers in scientific courses of study is positive at the secondary level, where it has increased, but progress has been more ambiguous at the post-secondary level.	1. An insufficient representation of girls and women in STEM fields because of educational policy and information campaigns on parents, teachers, guidance staff and girls. Personal, contextual and social cognitive factors have an impact on the formation of interest (p. 553). Educational policy should be used to diversify girls' educational pathways and direct them towards scientific courses and jobs. 2. Girls are more likely to choose subjects where their gender is well represented. Classroom interactions between teachers and students, assessment styles and curriculum content result in the lower self-esteem of girls and gender-different attitudes within various areas of knowledge.
Chatoney, M., & Andreucci, C. (2009).	The study attempts to discover what impact can be produced by a study support object which is socially associated with one gender or the other in middle school technology teaching.	Ages 13 and 14	Two empirical studies. The first is a pre-investigation of the feminine, masculine or neutral gender attributed by pupils to study support tools. Results confirmed whether teachers consider the effects their choices have on the gender of the group they are teaching. The second is an experimental study of pupils' attitudes in an artefact design situation, the usage of which is primarily socially defined, and in which girls and boys may proceed differently. It is more specifically a matter of highlighting the effects produced by feminine and masculine artefacts upon girls' and boys' learning. Feminising technology does not take anything away from learning for boys.	1. "Certain contents, certain types of activities, certain forms of studies, certain gestures of education and scholastic shapes are better adapted to the girls than to the boys and conversely" (p. 393). Girls often seek help in technology from boys: "Girls, who are more inclined to totally re-invent the product (goal) and move away from the prescribed task, strictly speaking, or simply develop solutions which do not exist elsewhere (jewellery box)" (p. 401). 2. Girls prove to be more sensitive to the study aids they are working with. They show greater imagination and inventiveness and take more risks than boys on the feminine supports that they are familiar with. They act in a similar way to boys, however, when working with masculine supports. The concept of technology is not defined but the task performed in the study was a product improvement of a Mini football cage and a jewellery box.

Rasinen, A., Virtanen, S., Endepohls-Ulpe, M., Ikonen, P., Ebach, J., & Stahl-von Zabern, J. (2009).	The aim was to discover the strengths and weaknesses of Finnish and German curricula and systems of organizing technology education. Another objective was to identify gender-related reasons why girls drop out of technology and lose interest in technological careers.	Ages 7–12	Questionnaire study and curriculum analysis. Questionnaire study results on the attitudes and self-efficacy of boys and girls indicate that, already at this young age, girls are less interested and do not feel as competent as boys. “Results of the studies conducted in the UPDATE project showed that influences on interest in technological themes take place already in early childhood. Therefore, efforts should be made in developing early childhood education and elementary school education, to raise girls’ interests and motivation towards technology” (p. 367).	1. An insufficient representation of girls and women in the field: “There are still remarkable gender differences in the number of males and females studying and working in the technological fields” (p. 368). The process of females drifting away from the field of technology starts at an early age. If children at this age, especially girls, think that activities in the field of technology are not suitable for girls, this will naturally be a barrier to making these topics appear interesting or relevant (p. 375). 2. “Girls in particular need to experience appreciation of their technical competences by their teachers. Technical activities conducted in class should be presented in a way that enhances girls’ self-confidence in technology. Female teachers especially (and this is the majority of primary school teachers in all European countries) should act as positive role models for girls by demonstrating their own technological competence” (p. 378).
Sheffield, R., Koul, R., Blackley, S., & Maynard, N. (2017).	Examines how a Makerspace approach can capture the imagination and creativity of female primary school students, and engage them in integrated STEM-based projects.	Years 5 and 6	An exploratory case study to examine participant engagement with and reflections on a Makerspace in a STEM project. The authors do not claim that the Makerspace in a STEM project is by itself the best way to engage girls in STEM. However, they do suggest that there is much more to gain from treating STEM learning in this space as more than a purely cognitive matter, and stress that including affect and motivation is intrinsic to STEM spaces (p. 162).	1. Women hold a disproportionately low share of STEM undergraduate degrees, particularly in engineering, and those with a STEM degree are less likely than their male counterparts to work in a STEM occupation (p. 151). There should be a greater inclusion of women in STEM fields. Girls’ engagement is described as though they are not interested, or that they do not have knowledge of technology. Girls will, for instance, be more motivated and engaged when empowered to participate on their own terms and when they receive positive feedback. 2. The technological activity that the girls were in-

				volved in included electric circuits that were used in a performed task, which was to create a bag.
Master, A., & Meltzoff, A. N. (2016).	The aim is to show that it is possible to increase equity and enhance outcomes for a broader number of children around the world by integrating psychological and educational science.	4 and 6 year-olds	Investigated two ways to encourage young children's interest and motivation in STEM. Designed interventions were based on: (1) increasing experience and (2) providing social information about what other "in-group" members do. First interventions: Programming a robot using a smartphone was one described task. Another task was constructing a Lego robot. Second intervention: boost children's motivation for performing a STEM task by having them complete this task as part of a group versus as an individual. In the findings, authors argued that girls' underrepresentation is not due to an intractable, immutable lack of interest or ability. Instead, girls' choices are driven by sociocultural factors; for example, stereotypes about who typically does STEM and who has ability in STEM.	1. Girls report lower interest and self-confidence than boys in STEM in most countries and perform worse on standardised STEM tests in some countries. Women are less likely than men to earn STEM degrees and work in STEM careers. Cultural stereotypes are present in children's minds and begin to shape their beliefs about what field is for them and where they belong. 2. Girls' non-engagement is not due to an intractable lack of interest or ability.
Shoffner, M. F., Newsome, D., Barrio Minton, C. A., & Wachter Morris, C. A. (2015).	The purpose was to increase our understanding of one aspect of the early career development of young people, as they form opinions and develop perceptions about career options in STEM.	Ages 10 –14	Qualitative study using focus group data to examine the outcome expectations, what young people believe will happen if they pursue certain interests, tasks, or goals. Study indicates that female students often experience a decline in self-esteem in the transition to middle school and during the subsequent middle-school years. When spoken to about future careers, girls were more likely than boys to focus on proximal outcomes, such as doing well in school, failing, or needing to spend a lot of time on homework. Result - "be aware of the negative outcome expectations that may be driving students' choices, because many of these expectations may be irrational or misinformed" (p. 113).	1. "The importance of relationships and connectedness to identity development in girls and young women" (p. 111). Outcome expectations are described as important factors in the development of young people's interest in future careers and their goals for careers. 2. Whereas both boys and girls talked about internal motivation and intellectual stimulation, girls were more likely to discuss psychological effects. (p. 111)

Chang, S., Yeung, Y., & Cheng, M. H. (2009).	The purpose is to investigate students' learning interests and life experiences involving science and technology, and also their attitudes towards technology.	Ninth graders	Likert-scale questionnaire, developed from the ROSE project. Results indicated that boys showed higher learning interests in sustainability issues and scientific topics than girls. However, girls recalled more life experiences about science and technology than boys. "One surprising finding was revealed in this study, that is girls' life experiences about S&T were higher than boys, like the sustainability issues of environment, earth science, biology and information technology, and only earth science was no significant difference." (p. 454)	1. Girls need to be promoted in science and technology. Even though immersed in the subject matter of science from an early age, female students "all described later feelings of alienation, of being 'cut off' from the possibility of developing a deeper, more 'adult' relationship with science" (p.449). Girls have more experience relating to S&T than boys, but do not feel interested in learning S&T (p. 454). 2.Only girls' relationship to technology is discussed as being in need of support.
Voyles, M. M., Fossum, T., & Haller, S. (2008).	The study addresses: "(1) Do teachers differ in the way they interact with fourth- through sixth-grade boys and girls who are working in same-gender triads to learn engineering and computer programming in a robotics course? (2) Do boys and girls in a technology course differ with respect to interest, prior experience, achievement and self-confidence, cooperation, and requesting help?" (p. 323).	Grades 4, 5, and 6.	Study perspective is "gender difference, where the goal is to identify the ways in which male and female students differ or are treated differently, and to suggest ways to address these differences" (p. 327). Analysed transcripts of videotapes of instruction; teacher, parent, and student interviews; student questionnaires; and final programmes. The results showed that girls and boys differed in several ways, and teachers explained their differing interactions with boys and girls as functional responses to those differences. At the end of the course, volunteer boys and recruited girls did not differ in achievement or interest in the course.	1. Women not pursuing careers in technology is seen as a problem. Factors other than personal preference discourage women from entering STEM fields. 2. Girls were more likely than boys to initiate interaction with teachers. Findings could be interpreted to mean that the girls were less able and needed more assistance than boys. However, it is also possible that more able or conscientious students have the confidence and good judgment to ask critical questions (p. 340). The task performed in the study was building and programming a Lego Mindstorms robot.
Villas-Boas, V. (2010).	The aims were to improve the	High	This project was planned to provide a foundation for	1. "Unfortunately, most girls do not consider a career

	quality of the teaching and to increase the interest of students in technological areas, leading to a future career in engineering.	school level students.	the teaching–learning process of science and for the application of theory in the solution of real problems. Activities based on "new educational methodologies, workshops in different areas of science and technology, a programme entitled 'Encouraging girls in technology, science and engineering'" (p. 289). "For the moment, there are no quantitative results on the increase of students choosing engineering courses at UCS nor on the increase in women choosing engineering as a career since activities of this project only started at the beginning of 2009. However, the enthusiasm shown by participants in the programme suggests that measurable results will soon be forthcoming" (p. 295).	in these fields, in which females are underrepresented. The problem starts early, with society stimulating girls to take an interest in subjects said to be 'feminine' rather than 'masculine'" (p. 294). 2. Girls could become included if they were subjected to tasks "addressing problems at school and in the neighbourhood, working with tools, building robots, taking field trips, etc. (p. 294).
Fensham, P. J. (2009).	Discusses issues arising from the use of S&T contexts in PISA and the implications they have for the current renewed interest in context-based science education	15-year-olds	Analyses of the students' responses using the contextual sets of items as the unit of analysis provides new information about the levels of performance in PISA 2006 Science. Embedding affective items in the achievement test did not lead to gender/context interactions of significance, and context interactions were less than competency ones. (p. 884)	1. Girls are not engaging with technology education. A suitably chosen real-world context can engage both boys and girls. (p. 884) 2. The written PISA test was perceived to be of great advantage to girls because of their known better performance in reading in most of the participating countries.
Virtanen, S., Räikkönen, E., & Ikonen, P. (2015).	Explore differences between girls' and boys' motivation in relation to technology education in primary school.	Ages 11–13 years	A questionnaire was administered to pupils in grades five and six. Factor analyses showed that pupils' motivation structure consisted of nine factors. The results also showed gender differences in most factors.	1. Girls were seen to be lacking in the field of technology. Girls were significantly more interested in studying environment-related issues. Interest in this context refers to choosing something among alternatives or favouring something over its alternatives. (p. 200) 2. The girls felt that it was fundamental to obtain support and encouragement from teachers. Additionally, girls enjoyed making useful and decorative artefacts for their homes more than boys.

Jennings, S., McIntyre, J. G., & Butler, S. E. (2015).	Exploring young adolescents' interest in engineering as a future career by examining the influence of gender and grade level on participants.	Ages 10–13	Video intervention, questionnaire and qualitative analyses. Qualitative analyses comparing the responses of participants who had seen a video, with those who had not, revealed that the video dispelled some stereotyped beliefs, but not others, with grade-level and gender effects. Results highlight the importance of listening to adolescents' views about engineering as a field and as a future career.	1. Girls appear to be less interested in STEM than boys: "Interactions between gender and age influence the consideration of engineering as a possible career" (p. 15). Programmes to promote girls' interest in technology are failing. 2. Girls, more than boys, were hypothesised to report feeling differently about engineering after seeing the video. Girls, more than boys, exposed to the video were hypothesised to comment positively on engineers as "helpers".
Autio, O., Olafsson, B. & Thorsteinsson, G. (2016).	Explore students' technological knowledge and reasoning.	Ages 11 and 13.	A questionnaire regarding mechanical systems connected to simple physical phenomena. Results highlighted that students should have been more familiar with the content of the survey as a result of their Design and Craft studies and the use of textbooks in other subjects, such as physics. Differences between boys and girls are explained by their different interests and this has an impact on girls' motivation for learning about technology.	1. The insufficient representation of girls and women in STEM fields might be because of the different social expectations for boys and girls. Furthermore, it is not a surprise that boys and girls differ in their interests (p. 65). 2. Icelandic girls who scored better than their peers are thought to have a better setup for scoring higher due to the curriculum.

Dakers, J. R., Dow, W. & McNamee, L. (2009).	Explore perceptions that are held by school students about technology and technology education when they enter secondary school.	Ages 12–13	Case study undertaken in the UPDATE project. No gender difference emerged, either from the questionnaires or from observation in the amount of enjoyment or engagement displayed by pupils. Both boys and girls were highly motivated and engaged throughout. It is argued that technology education is perceived to be masculine in nature, procedural in delivery and lacking in the conceptual dimension. “The findings suggest that where technology is not perceived of as masculine in these respects, and where new forms of pedagogy that integrate or fuse conceptual issues relating to technology into the learning space are employed, then girls and boys seem to develop more interest in the subject matter” (p. 390).	1. “Girls and boys are no longer streamed into either domestic science or technology subjects on the basis of gender. These boundaries, it would appear, have been dismantled. The fact remains, however, that despite these progressive shifts in policy, girls, in general, still orientate towards food or textile technology areas” (p. 385). “More girls achieve higher grades in virtually all technology subject domains. It is therefore clearly not a question of lack of ability on the part of girls” (p. 386). 2. “No gender difference emerged, either from the questionnaires or from observation in the amount of enjoyment or engagement displayed by pupils. Both boys and girls were highly motivated and engaged throughout. Boys and girls collaborated very well, both within and across groups in their attempts to find a fragrance which would meet the approval of the opposite sex” (p. 390).

Summary of the results

Girls' engagement with technology education

When describing gender and technology, most studies report that girls are less interested than boys, and that female students tend to have less ambition in technology and are underrepresented in the field (Jennings, McIntyre, & Butler, 2015; Chang et al., 2009; Ardies, De Maeyer, & Gijbels, 2015; Ardies, De Maeyer, Gijbels, & van Keulen, 2015; Villas-Boas, 2010). Some studies (Ardies, De Maeyer, Gijbels, & van Keulen, 2015; Master & Meltzoff, 2016; Rasinen et al., 2009) also report that girls are interested at the age of around 10, but from that point onwards their interest starts to decline. Girls also tend to be more negative towards technology, according to some studies (Ardies, De Maeyer, & Gijbels, 2015; Shoffner et al., 2015). Girls are thus generally more negative towards technology, whereas boys are found to be more positive than girls and with a less negative trend in the development of their attitudes.

Some studies (Mammes, 2004; Autio & Soobik, 2017; Andreucci & Chatoney, 2017; Chatoney & Andreucci, 2009; Autio et al., 2016) conclude that the low level of interest among girls is traceable to their socialisation, the different social expectations for boys and girls, and to the fact that girls are not exposed to technology as much as boys. Girls' lack of interest is thus seen as a social construction. People treat girls and boys differently from an early age, giving them different feedback and expectations, and culture discourages girls from being interested in technology even when they demonstrate talent for pursuing science and technology careers.

According to many of these studies (e.g Ardies, De Maeyer, & Gijbels, 2015; Stevanovic, 2014; Rasinen et al., 2009; Autio et al., 2016; Virtanen et al., 2015), there is also an insufficient representation of girls and women in the STEM field. Women hold a disproportionately low share of STEM undergraduate degrees, particularly in engineering, and those with a STEM degree are less likely than their male counterparts to work in a STEM occupation. The process of females drifting away from the field of technology starts at an early age, around 10. If children at this age, especially girls, think that activities from the field of technology are not suitable for girls, this will naturally be a barrier to making these topics appear interesting and relevant.

Girls will also be more motivated and engaged when empowered to participate on their own terms and when they receive positive feedback (Chatoney & Andreucci, 2009; Virtanen et al., 2015). Girls report lower interest and self-confidence than boys in STEM in most countries and perform worse on standardised STEM tests in some countries (e.g. Fensham, 2009; Chang et al., 2009; Osagie & Alutu, 2016; Dakers et al., 2009). Women are less likely than men to earn STEM degrees or to work in STEM careers. But, as argued by Master and Meltzoff (2016), girls' underrepresentation is not due to an intractable, immutable lack of interest or ability.

Chang, Yeung, and Cheng (2009) conclude that girls have more experience related to science and technology than boys, but still they do not feel interested in learning about the area. Another study (Virtanen et al., 2015) claims that girls were significantly more interested than boys in studying, for example, environment-related issues, whereas a couple of studies find that girls are just as interested in or engaged with technology as boys (Dakers et al., 2009; Voyles et al., 2008).

Girls' technological activities and the relationship between girls and technology

This second part of our aim was more difficult to trace in the selected studies. The technological activities in which the girls were involved in the various studies include electric circuits that were used in a pre-set task to create a bag (Sheffield et al., 2017); a Christmas tree and components of the electrical circuit, and designing and making a nesting-box (Mammes, 2004); a product improvement of a Mini football cage and a jewellery box (Chatoney & Andreucci, 2009); and building and programming a Lego Mindstorms robot (Master & Meltzoff, 2016).

According to Ardies, De Maeyer, & Gijbels (2015), gender differences in technology may correlate with the presence of technological toys and the amount of actual play with such toys. Autio and Soobik (2017) claim that technological knowledge is important, especially in spatial reasoning, and that this has an impact on girls' motivation for learning about technology. Girls prove to be more sensitive to the study aids they are working with. They show greater imagination and inventiveness and take more risks than boys on the feminine supports that they are familiar with (Mammes, 2004). They act in a similar way to boys, however, when working with masculine supports. Girls were much more likely than boys to initiate interaction with teachers (Voyles et al., 2008; Virtanen et al., 2015). This finding could be interpreted to mean that the girls were less able and needed more assistance than the boys. However, it is also possible that more able or conscientious students have the confidence and good judgement to ask critical questions. Mammes (2004) also found that teachers can encourage girls to be interested in science and technology through how they teach.

Discussion

In this section, we discuss the results of our scoping literature review in response to our research aim. When analysing girls' engagement, activities and relationship with technology (education) – as presented in Table 1 and in the summary of the results above – there are some important points to make. First of all, in the great majority of studies, girls come out as insufficiently represented or reluctant to participate in technology, science and/or STEM fields, or they are less interested or more negative towards technology (education) than boys. A very important point to make here is that there is ample evidence supporting these claims (see Table 1); for example, from studies of students' attitudes towards technology, which have a long tradition in technology education (Ankiewicz, 2019; Ardies, De Maeyer, Gijbels, & van Keulen, 2015; Svenningsson et al., 2018).

Secondly, however, many of the studied articles venture explanations for why girls' engagement, interest and attitudes differ from those of boys, and those that do so offer two opposing explanations; either it is the girls themselves who are responsible for this, or it is societal prerequisites or expectations of various kinds that are to blame. In the former case, there are no further elaborations other than claiming that girls are less interested in and more negative towards technology than boys (Ardies, De Maeyer, Gijbels, & van Keulen, 2015), or that "girls, in general, still orientate towards food or textile technology areas" (Dakers et al., 2009, p. 385). In the latter case, which actually accounts for a majority of the 20 articles, there are attempts to explain, with reference to cultural and societal norms and expectations, why girls are less likely to choose technology or STEM fields, or just generally have a less positive attitude towards technology. The following are some examples: socialisation, that is, girls have not been exposed to as much technology as boys (Mammes, 2004, p. 91), or have been exposed to different social expectations than boys (Autio et al., 2017, p. 201); "social and cultural distribution of activities between men and women" (Andreucci & Chatoney, 2017, p. 5); "that the culture discourages girls" (Osagie & Alutu, 2016, p. 234); because of educational policy and information campaigns influencing parents, teachers, guidance staff and girls (Stevanovic, 2014); "certain contents, certain types of activities, certain forms of studies, certain gestures of education and scholastic shapes are better adapted to the girls than to the boys and conversely" (Chatoney & Andreucci, 2009, p. 393); "sociocultural stereotypes associating STEM with males act as barriers that prevent girls from developing interests in STEM" (Master & Meltzoff, 2016, p. 215); "the importance of relationships and connectedness to identity development in girls and young women" (Shoffner et al., 2015, p. 111); "girls do not consider a career in these fields, in which females are under-represented. The problem starts early, with society stimulating girls to take an interest in subjects said to be 'feminine' rather than 'masculine'" (Villas-Boas, 2010, p. 294); and girls also feeling that it is fundamental to obtain support and encouragement from teachers (Virtanen et al., 2015).

There are, of course, exceptions here. For example, Ardies et al. found that girls are more positive towards STEM than technology, which was the same as boys (Ardies, De Maeyer, & Gijbels, 2015); teachers can encourage girls to be interested in science and technology through how they teach (Mammes, 2004); and a couple of studies also found that girls are just as interested in or engaged with technology as boys (Dakers et al., 2009; Voyles et al., 2008).

Regarding girls' technological activities, few articles define the concept or type of technology (activity), although those studies that do define a type of technology that is put forward as either neutral, or a "male" kind of technology (e.g. electrical gadgets, electronics or Lego Mindstorms). Exceptions are Chatoney and Andreucci (2009), who refer to a jewellery box, and Andreucci and Chatoney (2017), who take up examples of activities involving artefacts that can be considered as both male and female. The last part of our aim, the relationship between girls and technology, is scarcely described at all in the included studies. However, girls indeed do have a relationship with technology, and it seems that, although girls' engagement with technology and STEM fields is lower than boys', there is potential for improving this engagement using apparently simple means. For example, girls are more sensitive than boys to the "gender" of study aids/support objects that they are working with in a design project, as shown by Chatoney and Andreucci (2009). Girls also show greater imagination and inventiveness, and take more risks than boys, with a feminine study aid (jewellery box). Mammes (2004) also concludes that teachers can encourage girls to be interested in science and technology through how they teach, and that this is easier the earlier technology education is introduced in school. The existence of female teachers and female classmates is also important for improving girls' engagement, and could thus lead to a positive "snowball effect" (Stevanovic, 2014; Rasinen et al., 2009).

Our analysis of the data about girls' engagement with technology education was made difficult by the scarcity of information in the reviewed articles (see Table 1). However, by performing a content analysis, we have nevertheless unearthed some structures, symbols, and identities as being prevalent in the research on gender and technology. To some extent, the research reveals a traditional view of what technology is – a concept of technology and empirical examples of types of technology with a typical male, "nuts-and-bolts" code. Questionnaires, for example, could contain questions that prompted the following remark: "Spends a lot of time with engineering-related hobby activities" (Autio et al., 2016, p. 98), which can be seen as a male-coded form of technology. This might generate misleading answers from girls who do not identify their engagement in technology as engineering. When revisiting the PATT questionnaire, Svenningsson et al. (2018) also discovered that the gender category cannot be used as intended since it might be gender-biased; in the gender items, boys were consistently placed before girls; for example, “Boys are able to do practical things better than girls”. There thus seems to be a mismatch between the image of girls as not engaged in technology and that of expecting them to be so engaged, although most of the studies in the sample acknowledge that the reasons for this disengagement are beyond girls’ and women’s control. However, the gendering that takes place within a research discourse seems to be complex as well as conflicting, which invites further detailed empirical research.

In conclusion, according to the reviewed studies, girls are less interested and have less positive attitudes towards technology (education) than boys. They are also less likely to choose a technology or STEM-oriented occupation. Several of the included studies venture possible explanations as to why this is the case, and refer mainly to cultural factors. Those studies that do define the type of technology used in girls’ activities mostly describe a neutral, or male kind of “nuts and bolts” technology. As regards girls’ relationship with technology, there is potential for improving female engagement using apparently simple means; for example, making sure that the social context of teaching is adapted to girls.

Limitations and further research

The potential limitations of this study were the manner and timing of the ERIC search, which can generate varying results despite applying the same search variables. As Hussénius, Andersson, Gullberg, and Scantlebury (2013) argue, too many studies are restricted to comparing female and male students and it could also be valuable to perform studies focusing only on girls in order to change the perspective. Techno-feminist theory highlights the co-construction of technology *and* gender. Gender relations are materialised in technology, which in turn gives meaning not only to gender relations (Wajcman, 2010), but also to girls’ and boys’ engagement with technology separately. Therefore, focusing future research on girls and technology could provide important insights that go beyond a comparison with boys and men. Furthermore, the studies reviewed were mainly conducted in a Western context and by Western researchers. Key results from the Rose project (Sjøberg & Schreiner, 2010) highlight girls in countries like Uganda, Ghana, Lesotho, Swaziland, Zimbabwe and Botswana as having the most positive attitudes to technology and technology-oriented occupations. This positive attitude could be of interest to explore. Data and analysis from a cross-cultural perspective as grounds for discussions and conclusions concerning gender structures and gender symbols and identities could be very illuminating.

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Makerspaces for Pedagogical Innovation Processes: How Finnish Comprehensive Schools Create Space for Makers

Juha Jaatinen, University of Turku, Finland

Eila Lindfors, University of Turku, Finland

Abstract

Finland has its own version of a "makerspace": craft class. Originally, there was one craft class for boys and one for girls. Later, there were classes for different materials, especially for wood and textiles, which are deep-rooted concepts in the Finnish crafts mindset. To reclaim craft class for pupils, or "makers", we must determine teachers' and pupils' mindsets concerning collaboration, differing interests and sharing. Craft is a compulsory learning-by-doing subject for pupils in grades one through seven, with activities based on craft expression, design and technology (CDT). This research is part of a national endeavour to develop innovative CDT as a basic education subject. The paper explores two pilot case studies in which technical and textile work teachers taught together in a shared learning environment, rather than in traditionally separate learning environments. The aim was to develop criteria for a new kind of learning environment that would promote learning to develop innovations and pupil's innovation competencies. The first study used a mixed methods approach, including systematic observation, inquiry and pair interviews of five co-teaching teams in primary school, to test the new teaching culture. The second study used an experience sampling method in the form of a mobile application to reveal various parts of pupils' design and making processes in a school setting. The key finding is that collaborative teams can support teachers' and pupils' innovative learning activities when the work is supported by shared spaces, practices and new tools. The paper concludes by relating preconditions for implementing makerspaces in the context of formal comprehensive education to learning outcomes, traditional workshops, learner differences and pedagogical innovation processes.

Keywords

makerspace, basic education, school reform, co-teaching, self-assessment, pedagogical innovation process

Introduction

Earlier studies give us a broad perspective of good learning environments. Well-being in schools is based on school conditions, social relationships and means for self-fulfilment and health (Konu & Rimpelä, 2002). Learning environments should be safe and reflect connections to the surrounding society (Piispanen, 2008). Good learning environments also depend on teachers' active collaboration in the design process (Nuikkinen, 2009). Successful teacher communities require supportive leadership, trust and respect for professional development and effective group dynamics and compositions (Vangrieken, Meredith, Packer, & Kyndt, 2017). Finally, learning environments should support the use of modern teaching and learning processes (Kuuskorpi, 2014, 2012). All of the above are critical considerations when creating a space or environment to facilitate learning.

Spaces for hands-on learning and learning by making in formal and informal education—so-called "makerspaces"—have gained global prominence since the advancement of digital modelling and fabrication. 3D printing, laser cutting and other computer numerical controlled (CNC) devices have been used as means of concretising innovative ideas, even with young learners (e.g. Halverson & Sheridan, 2014). However, making is not only about modern technology; it is also the primitive human obsession to use tools to survive in various circumstances. The history of mankind is a history of tooling and solving a variety of problems and challenges. Today, people's individual innovation competence allows them to acknowledge new problems and construct highly usable solutions as part of teams. Individual innovation competence is seen as a combination of personal characteristics, future orientation, creative thinking skills, social skills, project management skills, content knowledge and concretisation and implementation planning skills (Hero, 2019; Hero, Lindfors, & Taatila, 2017).

In many countries, traditional workshops for craft have either never existed or been removed from schools for various reasons (e.g. modernization, financial savings, a lack of appreciation or safety concerns). As a result, there is an insufficient culture of design and technology as a curricular subject. Finland has a unique tradition of makerspaces in comprehensive schools (7- to 16-year-old pupils). The Nordic tradition of teaching craft and technology as a subject in comprehensive education for all pupils (Johansson, 2018; Porko-Hudd, Pöllänen, & Lindfors, 2018) has guaranteed the existence of workshops in formal education as places of design and making since the 19th century. Originally, these makerspaces were segregated by gender, as the curriculum from 1866 to 1970 reflected contemporary society's agrarian labour division of men and women (see e.g. Marjanen & Metsärinne, 2019). Today, society calls for innovative solutions to serious problems in personal and work life. The National Core Curriculum for Basic Education 2014, launched by the Finnish National Board of Education (FNBE), defines learning as being based on observation and exploration of the built environment, mandating efforts to offer pupils contemporary ways to design and apply technological knowledge of their multi-material world in practice (FNBE, 2016). To participate as active members of society, pupils should have opportunities to learn how to deal with and survive new and complicated challenges, such as climate change. Therefore, instead of the earlier labour division-based workshops there is now a need for learning environments that can facilitate creative and innovative problem solving. The question is: What kind of learning environments, or makerspaces, will teach pupils to learn and develop their individual innovation competence?

Teachers, schools and local administrators play central roles in educational change when innovating education. The teacher's role goes beyond simply being involved in the implementation (Organisation for Economic Co-operation and Development [OECD], 2017): Teachers institutionalise the original initiation of educational change over time (Fullan, 2016). However, with studies focusing on the learning environment of workshops and makerspace development still very rare, it is important that the unique tools in future learning spaces, such as shared design practices and digital fabrication tools among other materials and techniques (Allan, Vettese, & Thompson, 2018) be researched and explored to ensure the initiation of educational change starts out from a solid foundation. The study in this paper aims to fill this gap by recognising facts and preconditions for the development of makerspaces as learning environments for formal comprehensive education.

Theoretical views on spaces of making

Learning outcomes and workshops

The Finnish National Board of Education (Laitinen, Hilmola, & Juntunen, 2011) assessed learning outcomes in the 9th (final) grade of comprehensive education. A substantial number of the pupils failed in the key objective areas of CDT, and learning outcomes were weakest in product design skills (Hilmola, 2011, pp. 14–16). According to the teachers, pupils designed products often or very often (74%), while nearly half (42%) of the pupils answered that they rarely designed products, though two-thirds of pupils had positive attitudes toward CDT as a subject. According to a more recent study (Hilmola & Autio, 2017), attitudes differ depending on which kinds of workshops (textiles or technical work) pupils study in. The study did not reveal what appealed to the pupils when working in various workshops: material technologies, processes, products, or ways of teaching. However, it is clear that there are differing perceptions of designing and making between pupils and teachers and that the learning environment has an impact on pupil attitudes.

Peer and self-assessment is an integral part of learning in CDT education or learning through making. When asked about peer assessment as a learning approach, only 10% of teachers and pupils believed that peer assessment was used often or very often (Hilmola, 2011, pp. 168, 175). According to Saarnilahti, Lindfors and Iiskala (2019), pupils used self-assessment in a narrow manner, and some did not see its meaning in their own work. On this basis, it seems that instruction is experienced differently by pupils and teachers. To see makers (in this case pupils) as identities and parts of communities of practice (Halverson & Sheridan, 2014), it is important to ensure that pupils play an active role in defining problems and challenges as part of the innovation process. If teachers decide too many issues on behalf of pupils, there will be no ongoing holistic processes. On this basis, learning environments should nurture pupils' design activities and self- and peer-assessment skills, in addition to enhancing positive experiences through places for co-working and co-design. The surrounding material world lays a foundation for a sustainable way of living, and the educational task is to support pupils' well-being and life management skills (FNBE, 2016).

While investigating the learning outcomes of CDT, Lindfors and Hilmola (2016) identified three different groups of pupils: positive achievers, positive underachievers and negative underachievers. Positive underachievers fail in their tasks, but still have positive attitudes toward learning. Negative underachievers fail in their tasks and have negative attitudes (Hilmola & Lindfors, 2017). From pupils' motivational point of view, there is a need to understand pupils' actions, likes and dislikes in more detail to support their competence development in makerspaces. Joint practice development is key to self-improvement (Hargreaves, 2014), and self-regulation is an important topic when defining learning tasks related to pupils' own technological and practical experiences (Metsärinne, Kallio, & Virta, 2015). In addition to social and physical considerations, information and communication technologies are important aspects of contemporary learning environments. Pupils' activities can be studied and supported in real time using mobile applications (Ketamo, 2009, 2011) based on theories of flow (Csikszentmihalyi, 1990) and the zone of proximal development (Vygotskij & Cole, 1978).

A makerspace as a formal learning environment in CDT education

Makerspaces are typically informal sites for creative production in art, science and engineering. In the context of arts education, the focus is on metarepresentational competence (Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe & Owens, 2014). According to Tan (2018), science education in engineering makerspace depends on three practices: playful components, highly authentic scientific practices and attention to tacit knowledge in learning. Creating something out of nothing and exploring one's own interests is central to so-called maker culture. According to Halverson and Sheridan (2014), the three components of the maker movement are a set of activities, makerspaces as communities of practice and makers as identities. Connecting design thinking to the theoretical notion of knowledge creation relates to makers' initial level of agency in determining the kinds of making in which they are engaged (Hughes, Morrison, Kajamaa, & Kumpulainen, 2019). According to Lefebvre (1991), a space is a social product: a complex social construction that affects spatial practices and perceptions. Research considers the processes of production, rather than the physical space itself. Space serves as a tool and offers places to develop shared practices. The maker movement is about making by hand—in the digital age—a set of tools and skills needed to fulfil basic intentions (Dufva, 2017).

A learning environment for learning-by-doing/making/developing supports an understanding of the operating principles of technology and consists of suitable and safe facilities, tools, machines, equipment and materials. Information and communication technologies (ICT) and projects that cross subject boundaries in cooperation with experts and communities outside school offer many new possibilities (FNBE, 2016). In the Finnish context, traditional craft workshops are well suited for learning with several themes. Technical workshops typically include a basic workplace (one side of a workman's bench) and various workstations and workshops, usually for computer aided design (CAD), robotics, electronics, woodwork, machine tools, metalwork, plastic work, finishing, heat treatment and storage. Textile workshops are more like studios, equipped with basic workplaces and workstations for sewing, seaming, knitting, weaving, printing and sewable electronics.

In CDT, the learning environment is also considered a working environment because of the tools and machines used as a part of the pedagogical working processes. This adds to the conversation concerning safety issues in the form of criteria for safe and secure CDT makerspaces. In this way, safety culture is a relevant part of spaces for making. Safe and appropriate movements between basic workplaces and workstations/work areas/separate workshops impose certain conditions on building technology and managing noise, dust, machining waste, chemical emissions and heat treatment. In the formal school context, productive actions should follow the current curriculum and prepare for the future.

Support for pupils' different interests and processes

Pupils' abilities, skills and learning processes vary; thus, in managing a holistic design process, there is a clear need for timely support (Lindfors & Hilmola, 2016). Today, the Finnish core curriculum (FNBE, 2016) includes more innovative design processes than material technologies. In formal education, the Finnish makerspace focuses not only on the facilities of digital fabrication, programming and electronics, but also on the combined role of craft, design and technology in supporting pupils' personal growth and technological literacy. Instead of implementing either textile or technical work techniques in separate workshops, schools use a wide range of material technologies to invent and manufacture solutions for problems that pupils see as important and that educational authorities believe to enhance their innovation competencies.

One solution to support various kinds of pupils is co-teaching. Co-teaching is an instructional practice for teaching a heterogeneous group of pupils in the same space, and it involves active teacher participation in assessment, planning and instruction (Cook & Friend, 1995; Murawski & Lochner, 2011), as well as effective utilisation of the resources of the group and the interactions among the pupils. Co-teachers must manage different learners and ensure that all pupils have access to the content outlined by the curriculum. A shared makerspace can be seen as a microcosm of society, setting the tone for learning and community. In co-teaching, professional responsibility is shared and widens management of the whole learning environment. Professional co-teaching enables collective actions and dialogue spanning a zone of proximal development for teachers (Roth, Robin, & Zimmermann, 2002) and timely support for pupils in developing their innovation competencies. In CDT education, co-teaching allows teachers to learn from one another (e.g. unfamiliar material technologies and instructional approaches) and gives pupils more support in their design processes.

Supporting pedagogical innovation processes in a learning environment

Places for making, play a key role in bridging the humanities and the sciences, which is a complex problem (de Melo-Martín, 2010; Snow, 1964). Recently, the co-operation between these two sciences has increased, and innovative campus complexes have been developed to bring together different experts and views to facilitate innovations. However, higher education is far too late for pupils to begin learning innovation competencies. In comprehensive education, the pedagogical innovation process is a creative and reflective problem-solving, design, manufacturing and testing process for developing new solutions for various contexts. The process involves a user needs analysis, a problem definition (based on a learning task and user needs), ideation, critical testing of options based on ideas, usability development, prototyping, planning, making, fabrication and usability evaluations conducted through self-reflection and process and solution assessment, either individually or in a group (Lindfors, 2007, 2012; Lindfors & Hilmola, 2016). This innovative process develops contextual problem-solving skills and the critical optimisation of solutions in the material world (Lindfors, 2010). The process itself can also serve as a contextual learning environment (Hero et al., 2017), such that a pupil can invent a solution to a challenge at hand.

Traditionally, textile work is considered to be more human and aesthetically oriented, while technical work is, obviously, more technical (i.e. based more on natural sciences; Kojonkoski-Rännäli, 2001, 2006). In co-teaching, these two approaches form a perfect pair to actuate design thinking and technological literacy, as long as the work begins with the user's interest and supports pupils' different needs. However, solving tensions between instruction and construction when developing makerspaces is a common problem worldwide (Rosa, Ferretti, Guimarães Pereira, Panella, & Wanner, 2017; Tan, 2018). The quantity and range of the maker movement is defined by communities engaged in do-it-yourself activities. In the school context, learning is too often imagined to be orchestrated by instructors, rather than by hands-on makers, pupils or their own interests and experiences (Dewey, 1997). If pupils only passively respond to activities and events planned on their behalf, learning-by-doing and innovation competence development do not reach their full potential.

It is also important to consider who is in charge of a maker community and its organisation. Finnish teachers balance broad pedagogical freedom and responsibility. Local school curricula are planned and constructed by teachers, principals and municipal authorities according to the national basic education core curriculum, regulating pedagogical activities with various local interpretations (Simola, 2017; Toom & Husu, 2012). Teachers play a key role when deploying the maker movement in the context of formal comprehensive education. The recent studies (Hero, 2017, 2019; Hero & Lindfors, 2019) discussed developing innovation competence as a multidisciplinary activity system within the institutional higher education context. The findings suggest that conceptions of a learning experience in a multidisciplinary innovation project relate to: (1) solvable conflicts and unusual situations, (2) becoming aware of and claiming collaborative agency and (3) internalising the phases of the innovation process. The relevant factors for learning to develop innovation were categorised under six topics for guiding curriculum development and the pedagogical design of problem-based projects: competence factors, factors related to assessment, pedagogical processes, organising the activity, teachers' roles and opportunities for tutoring and using the concept in education.

The study context

The FNBE funded the Käsitäksää ("Do you get it?") project to pilot Finland's first elementary education makerspace that would allow co-teaching. The project unified traditional workshops into a coherent space for making. It also added digital modelling and fabrication machines. Pupils' basic workplaces and workstations for different material technologies were combined into a unified learning environment—a makerspace—instead of being divided into the traditional categories of textiles and technical work. The first author was in charge of the project coordination and the implementation of new ideas.

The study is based on two peer-reviewed pilot studies conducted in Finnish comprehensive education (Jaatinen & Lindfors, 2016; Jaatinen, Ketamo, & Lindfors, 2017). These two co-teaching case studies were interventions designed to solicit teachers' and pupils' perspectives and, thus, understand the preconditions for a makerspace. According to the norm of the Finnish comprehensive education core curriculum, pupils should be able to develop their innovation competence through CDT processes (FNBE, 2016). For example, CDT education can be carried out according to the following models: 1) shared craft education, 2) from technology to design, 3) from idea to product and 4) innovation processes (Lindfors, Marjanen, & Jaatinen, 2016; Lindfors & Hilmola, 2016). On this basis, a makerspace must enable, encourage and enhance various ways of teaching and learning CDT. For this reason, the main question of this study is: What are the preconditions for makerspaces enhancing pupils' pedagogical innovation processes in the context of formal comprehensive education?

The study context was a typical Finnish suburban primary school for grades one through six. The teachers involved in the study were primary school teachers with master's degrees, and three of the teachers also had CDT subject teacher degrees. Co-teaching and pupils' actions were observed in natural school study groups across three parallel classes of the same grade. Previously, a class of pupils was divided into two groups, which were taught one by one but switched between a textile teacher and a technical work teacher in the middle of the school year. The Käsitäksää project anticipated the implementation of the National Core Curriculum for Basic Education in 2014 (FNBE, 2016) by shifting the teaching system from individual teachers to co-teaching in the autumn of 2014. In the study context, several aspects of the learning environment (Manninen, Burman, Koivunen, Kuittinen, Luukannel, Passi & Särkkä, 2007, p. 15) were modified to support pedagogical innovation processes (Figure 1). This helped achieve the objectives of CDT teaching (FNBE, 2016) where the focus is on multidisciplinary and innovative holistic design processes.

First, the space for learning was organised to enable co-teaching (1st study: Jaatinen & Lindfors, 2016), and later, the interior was designed as a lounge based on ideas envisioned in teachers' and pupils' participatory workshops (2nd study: Jaatinen et al., 2017). Second, pupils' workplaces and different workstations and workshops were organised according to different phases of the flow in the holistic process, whereas previously a basic workplace was defined according to its material processing. Further, what was previously the supervisor's booth was transformed into the pupils' secret corner or ideation place. Third, the practice was developed to be more design-oriented, focusing on transversal competence and co-teaching. Fourth, the community was widened spatially and virtually to support natural connections to other subjects. Finally, following Wilson's (1996, p. 3) ideas of a constructivist learning environment, changes were made to the resources (e.g. the QR code instrument used in the second study).

Figure 1. Modified CDT learning environment

Methodology

The overarching aim of this research and development project was to develop a learning environment for pupils' pedagogical innovation processes in CDT education (Figure 2). To consider different perspectives on development, two studies were conducted in the context of Finnish comprehensive education. The research design sought to briefly summarise the two peer-reviewed pilot studies (Jaatinen & Lindfors, 2016; Jaatinen et al., 2017) and consider findings in relation to preconditions of makerspaces for formal learning environments in CDT education.

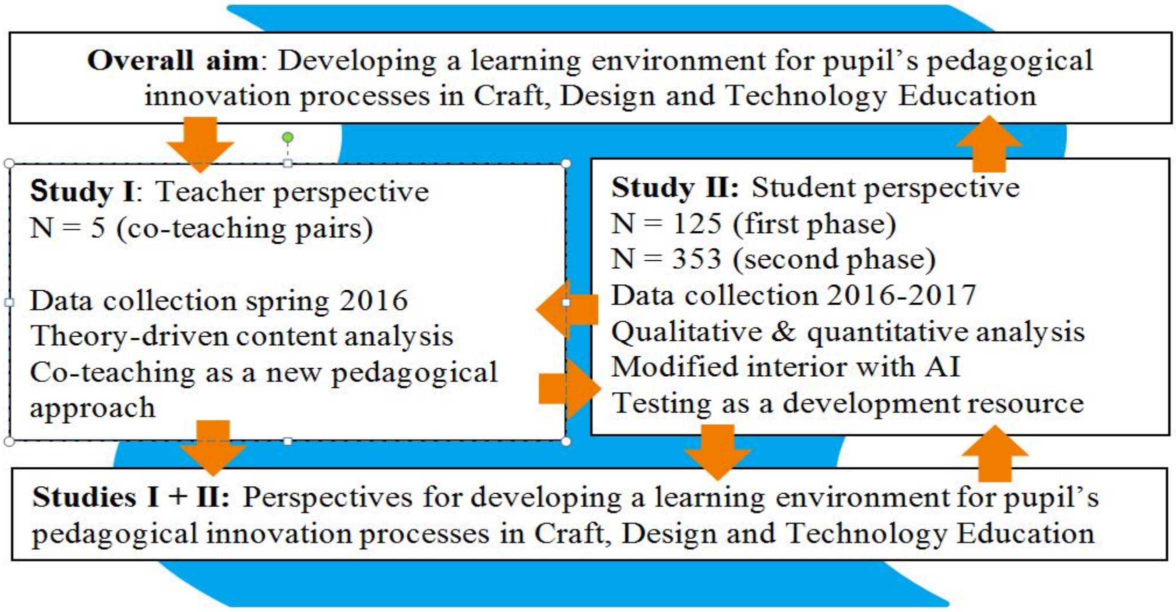


Figure 2. Research design

Study I: Co-teaching data and analysis

Co-teaching was used as a new pedagogical approach to find ways to enhance pupils' pedagogical innovation processes. The participants were five co-teaching pairs in primary school grades 3 through 6. Materials were collected based on triangulation with systematic observations (22 hrs, 2 to 6 hrs/team), individual inquiries and pair interviews of co-teachers (Figure 2). The study was conducted in the second year after the co-teaching started. The research design was created and adjusted based on Murawski and Lochner's (2011, 2014) work on observing co-teaching: what to ask for, look for and listen for. The framework was adapted to the Finnish educational context and content based on the work of Jaatinen and Lindfors (2016). The procedure was to observe the co-teaching, collect answers to inquiries and conduct interviews based on questions drawn from the inquiry. The research question was as follows: What is CDT education subject teaching when the approach is based on co-teaching? The data were analysed using theory-driven content analysis.

Study II: Experience sampling method and analysis of pupils' actions

In the second study ESM - an experience sampling method (Csikszentmihalyi, 2014; Hektner, Schmidt, & Csikszentmihalyi, 2007) with a gamified learning analytics instrument was used to examine a pilot implementation of a mobile application designed for use in the makerspace (Figure 2). There was a need for a method to reveal pupils' activities supporting and not supporting pedagogical innovation processes in the co-teaching setting. The mobile application was used as a new pedagogical approach that made it possible for teachers to challenge pupils' competence levels with increasingly difficult tasks.

Participation in the research was carried out in two stages. Teachers participated by collectively defining activities, and pupils participated by self-reporting their responses to activities. QR codes for the self-assessment application BOOK-AI were developed in the fifth and sixth grade teachers' workshop, and preliminary measurements were carried out in grades five through six (ages 10 through 12, n = 125) during a four-week period in 2016. The teachers' current teaching activities served as a backbone for the thematic mapping of the curriculum (Figures 3c, 3d & 5). The first four-week period was used to familiarise the pupils with the new ESM instrument and to detail measuring points for the holistic process. The list of pupils' learning activities was updated by all teachers involved in the CDT teaching. The updated list was tested in 2017, and materials were collected from all pupils in the project school (n = 353). The research question was: How are pupils' activities and progressions seen on a curriculum level when using information collected by a self-assessment application in activities defined by teachers? The analysis was conducted by introducing semantic maps of individual pupils' actions and progress and different kinds of group examples. This semantic network, built according to the keywords of the activities defined by the teachers and assessed by the pupils, is presented later in the document.

Studies I + II: Finding preconditions for a makerspace in CDT education

In the second phase of this paper, the results of studies I and II were considered in relation to the identified preconditions for a makerspace for a formal learning environment in CDT education. A review was conducted of theoretical views on spaces of making: learning outcomes, current workshops, ways of supporting various learners and pedagogical innovation processes. The research question was: What are the preconditions for makerspaces enhancing pupils' pedagogical innovation processes in the context of formal comprehensive education?

Findings

Study I: Jaatinen & Lindfors (2016) analysed co-teaching teams (two teachers, a teaching assistant and 18 to 21 pupils) in a learning environment that had been redesigned to promote pupils' pedagogical innovation processes. Based on theory-driven content analysis, the results of the study revealed that co-teaching was positively adopted as a new teaching approach. The results are presented by describing 11 core CDT co-teaching competencies (Table 1) and ways of mastering both emerging and developing co-teaching and proficient co-teaching. Co-teaching requires co-planning, co-instructing and co-assessing (Murawski & Lochner, 2011).

Emerging and developing co-teaching

The teachers involved in the study felt that co-teaching and multi-material craft were positive things from the pupils' point of view, even though these increased the requirements for teachers' skills. In light of the results (Table 1), it seems that the lack of planning time is a challenge in the emergence and development of co-teaching. Typically, in emerging and developing co-teaching, the learner and learning are not yet in focus, despite a shared learning environment. Tasks include selecting techniques for everyone (instead of organising peer interaction) and supporting holistic processes. Instructional practice suffers from a lack of own design know-how.

> *The lessons should be agreed and planned together in order, so that both teachers have a shared vision of how to proceed and which one presents and teaches certain issues, how the division of labour works, etc. Instructing a pupil's design is sometimes demanding depending on the pupils' differences… I need help with it. (Co-teaching pair 5.)*

Professional responsibility is not considered from a new co-teaching point of view. In emerging and developing co-teaching, teachers do not yet see the connection between learning tasks and holistic craft processes and cannot motivate challenging pupils. The prioritisation of design time into pedagogical innovation processes seems to depend on the teachers themselves.

> *The team of third grade teachers meets weekly. The team of fourth grade teachers meets at different times, leaving less time for co-design with teachers. (Co-teaching pair 1. & 2.)*

Table 1. Researching (structured observation, inquiry and pair interviews with inquiry themes) and developing the core competences of CDT co-teaching. Created and adjusted based on the work of Murawski and Lochner (2011, 2014). Content based on the work of Jaatinen and Lindfors (2016).

Emerging and developing co-teaching	*Proficient co-teaching*
I Teachers' commitment to a learner & learning	
1. Learner differences	
The same work instructions are given to all pupils, although they are at different phases of their process. Teachers do not recognise a need for individual support.	Pupils receive guidance according to their needs, and processes differ according to the development levels of their competencies.
2. CDT workshop environment	
Teachers do not share a common approach when a pupil's process is not proceeding as desired. Teachers do not discuss pupils' need for support.	Teachers treat each other with caring and respectful behaviours. Teaching supports and anticipates pupils' processes.
II Teachers' commitment to a task at hand	
3. Content knowledge	
There is a lack of consistent ideas concerning the whole lesson, and the guidance of pupils' design process is uncertain.	Teaching is based on formative assessment, and learning skills are consistently taught.
4. Compliance issues	
Interactive school support is absent, and the tasks required from all pupils have not been agreed.	Peer interaction is supported, and teaching is pupil-centred and implemented in co-operation.
5. Co-teaching construct	
Only a few co-teaching models are in use, and shared responsibility is not clear.	There are several co-teaching models in use, and the common guidelines form a coherent whole.
III Teachers' instructional practice in a pilot makerspace	
6. Assessment	
A pupil does not understand the meaning of evaluation, and there are no documents of the process.	Documentation is part of the evaluation process, and pupils' assessment is made in collaboration.
7. Planning	
There are few methods to guide design, and it is hindered by the teacher's own lack of design expertise.	Versatile co-planning methods are used to support pupils' holistic processes.
8. Instruction	
Pupils' self-regulation is taken for granted, and pupil grouping is not done appropriately.	Collaborative learning is based on motivational tasks, and peer collaboration is encouraged.
IV Teachers' professional responsibility in co-teaching	
9. Communication, collaboration & problem-solving	
There is no co-planning and no flexibility in technical or textile work teachers' roles.	Teachers use we-speech, and learning tasks are pupil-centred.
10. Families & community	
There is no cooperation with stakeholders; Only one teacher maintains e. g. contact with families.	Pupils' processes are visualised in a web for parents, and information is given in parents' meetings on pupils' progress.
11. Professional practices & ethics	
Teaching is dominated by material and technology centricity and is not based on transversal competence or pupils' holistic processes.	The beginning, educational entity and ending of a lesson are organised together to enhance pupils' smooth holistic processes.

Proficient co-teaching

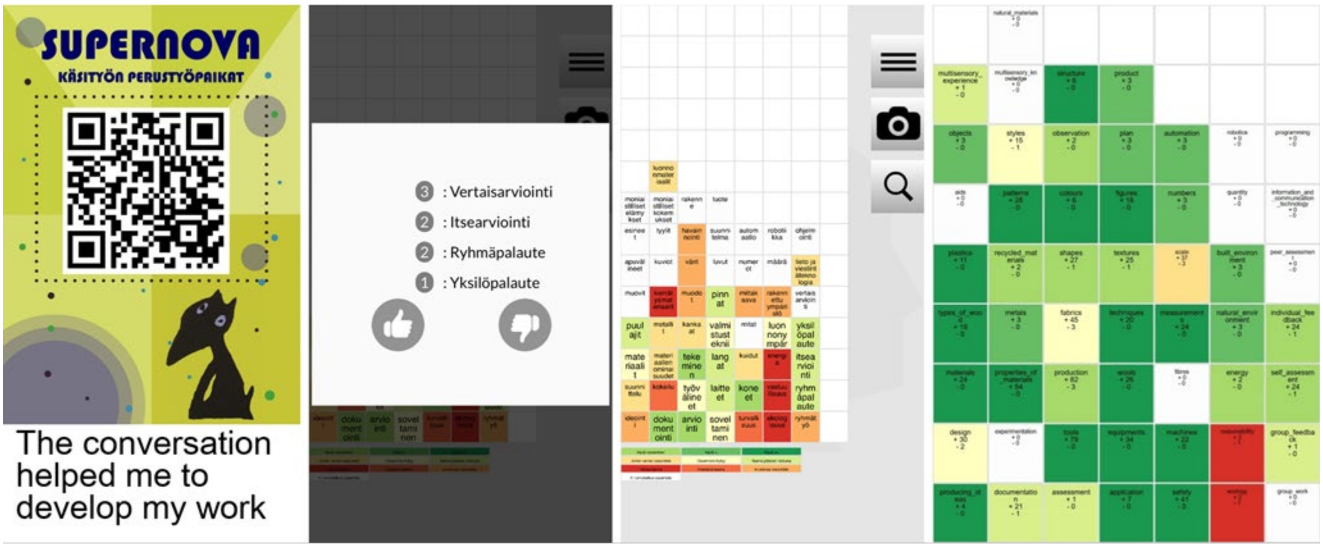
According to the results, interactive and collaborative planning, instruction and assessment for a pedagogical innovation process are key elements of proficient co-teaching. In proficient co-teaching, learner and learning are understood as learner-centred and common aspects of a shared learning environment. Tasks involve managing peer interaction and support for various and holistic processes. Instructional practice is manifold, and professional responsibility is a pride.

> *In early autumn, I was sceptical. Then I got interested in it, and I am in the more sceptical mode again. Multidisciplinarity provides opportunities, but it requires a lot from both teachers and pupils. (Co-teaching pair 3.)*

Conclusions from study I

The results suggest that higher CDT development targets (Hilmola, 2011; Lindfors & Hilmola, 2016) can be achieved through proficient co-teaching, including developing holistic process management and meaningful learning tasks for pupils. Pupils' activities should be developed to support more collaborative learning.

Study II: Jaatinen et al., (2017) investigated pupils' processes in CDT education by combining school architecture and a web-based learning environment (Figure 4). The aims of the study were to: 1) make pupils' CDT processes visible in everyday CDT workshop practices through information collected by a mobile application and 2) identify the curriculum topics covered during everyday learning activities. Individual tasks were connected to the larger conceptual framework. Figure 3a provides an example of a scanned QR code ("The conversation helped me to develop my work"). The learning objects are described by detailed rank-ordered keywords (tags, concepts) that define the themes of the content, as well as a difficulty estimator that describes the tags' estimated differences in terms of expectations of difficulty (Figure 3b). A pupil's level is shown in the data through a time series in ontology map (Figure 3c). The ontology map is essentially a personal profile that is coloured by users during use. The ontology map covers all concrete action-related concepts in local and national curricula. Initially, the blocks are coloured white, meaning that a concept has not yet been assessed. The blocks begin to turn orange at the first "thumbs up"; later, they turn to yellow to show good progress and green to show that a pupil has mastered a curriculum concept. A thumbs down turns a block's colour to red. The difficulty level is not meant to be strict and general throughout the network, and it must be accepted that there is relatively high uncertainty about estimated difficulty. However, at a conceptual level, the semantic network is very strict, and this difficulty in estimation is meant to strengthen this part of the network. Figure 3d presents group-level data for grade 6.



(a) (b) (c) (d)

Figure 3. a) A QR evaluation spot on a basic workplace; b) an action example (peer- and self-assessment, group and individual feedback); c) a pupil interface in Finnish, including main concepts in the local and national curriculum; and d) one example of group-level data visualisation using a 6th-grade group with many participants during a test (n = 21).

Workshops settings—towards a makerspace

The scanning of the architectural plan focused on the different actions of the key contents (Figure 4). At the start and end, educational entities and key content areas are discussed together. Basic workplaces offer a variety of actions, which were documented with own spatial arrangements in the studio. Different kinds of workshops for dirt, dust, heat and safety controls were equipped with work phase-related QR-evaluation spots. As this was a pilot study, it is impossible to draw far-reaching conclusions regarding what happened in each spot, and many user-related variables were unexamined. However, visualisations helped to reveal the relevance of different activities.

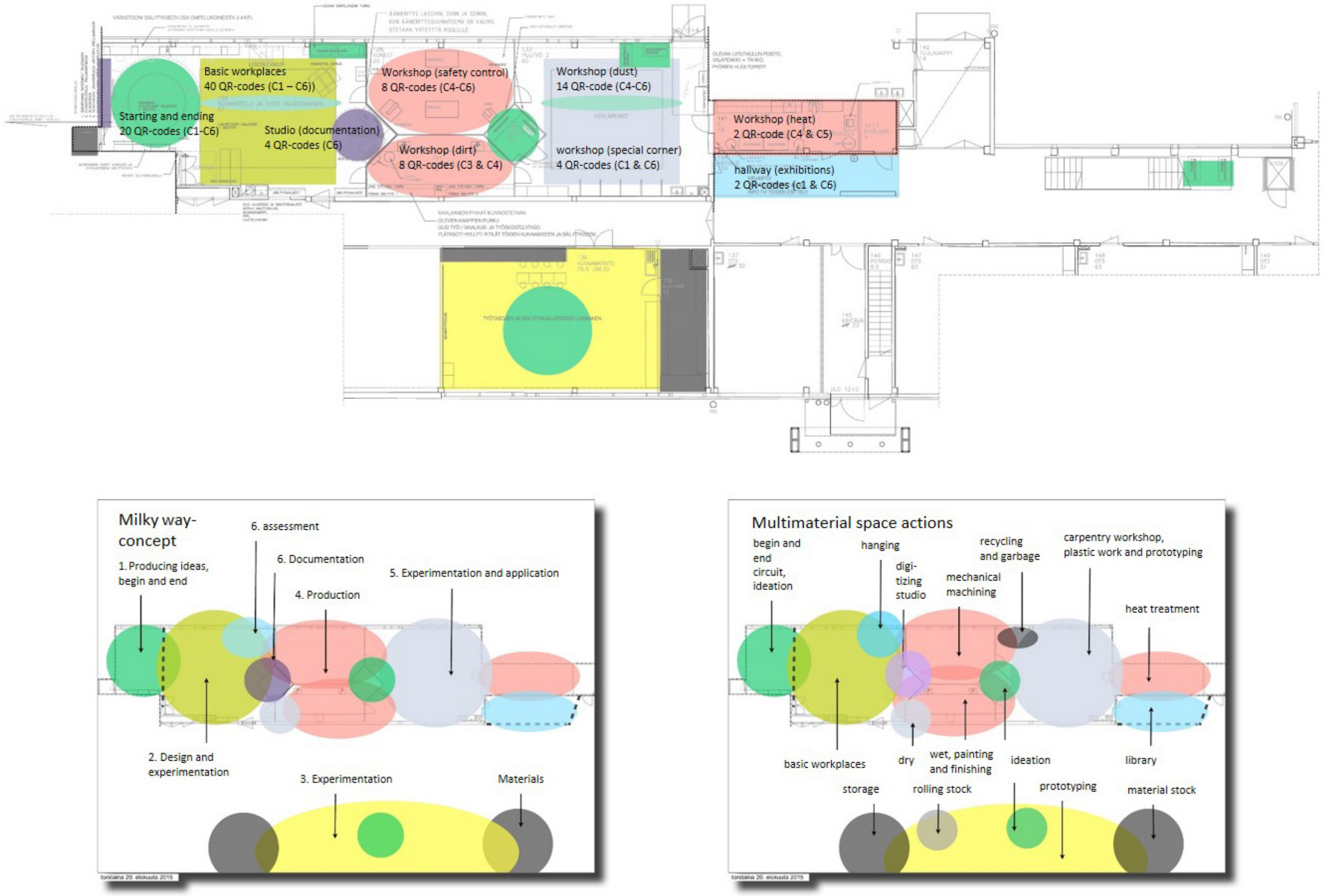


Figure 4: QR-evaluation spots in the pilot makerspace and main use of workshops during the 2nd test phase (Jaatinen et al., 2017).

Describing the learning activities

All concrete action-related concepts in local and national curricula are shown on the left in Figure 5 and organised according to occurrence by volume in the system's data mining. These concepts include (observe) objects, (use) scales, (experiment with) materials, (produce) products, (familiarise with) safety and (conduct) peer assessment. Activities are not emphasised on the regulation level. Data collected with ESM tools show the frequencies of the 54 curriculum keywords in the system over the course of the research period. Each activity was defined by several keywords. These form a set of words connected to one another via the activities, such that the keywords for each activity are all interconnected because they share the same activity-related meaning or purpose. The curriculum keyword is a fundamental concept. The keywords are connected via one or more activities. The semantic network is presented on the right in Figure 5 and the network was built according to the keywords of the activities defined for the second test phase. Most of the first defined actions related directly to the production phase. Design was linked to the actions (and, thus, evaluated), but it was not closely related to the production phase. However, the process did not focus on peer assessment, as it should in a maker community.

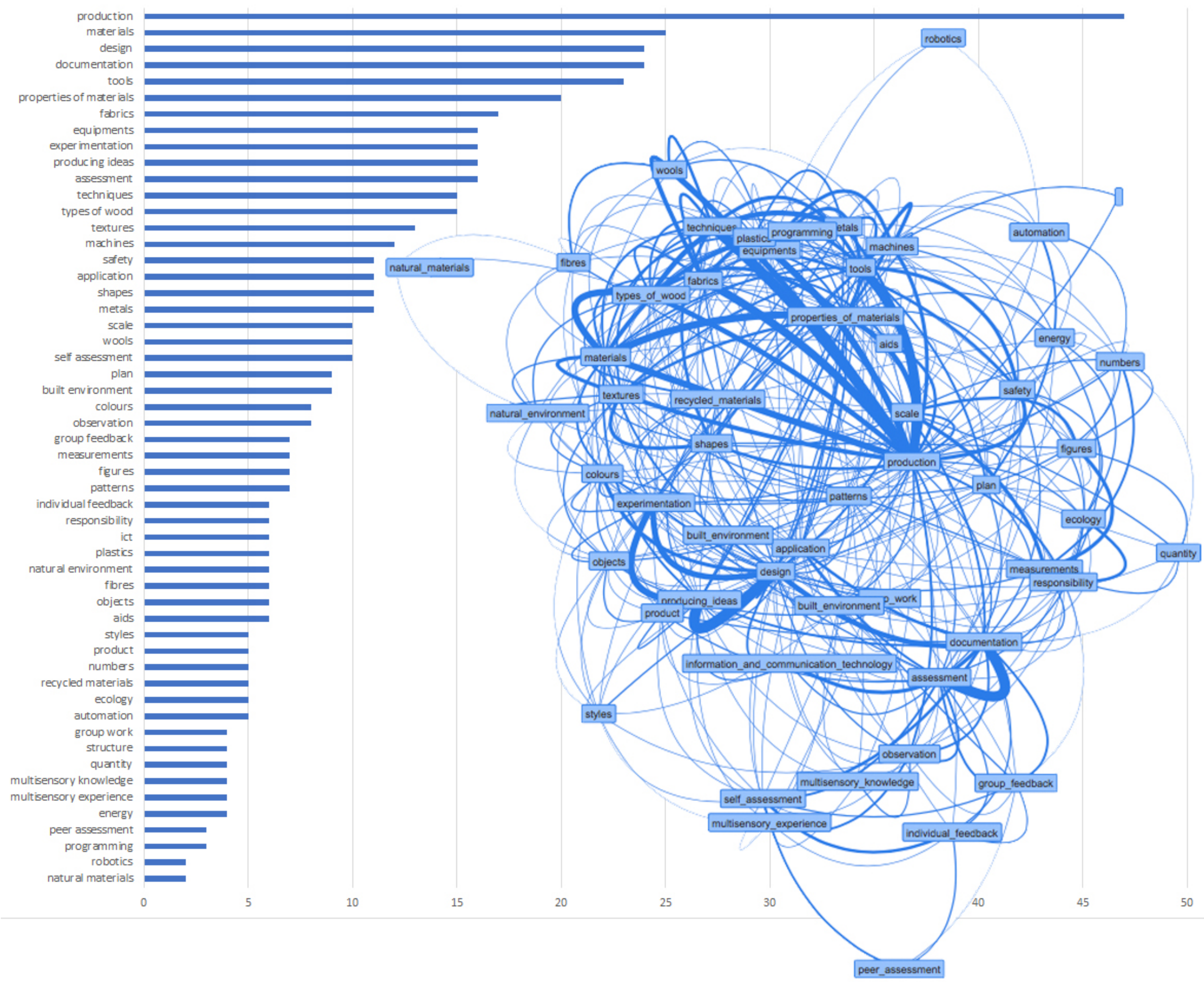


Figure 5. Left: the frequencies of the 54 curriculum keywords in the system. Right: a semantic network, built according to the keywords of the activities defined by teachers and assessed by pupils.

Conclusions from study II

The pupils considered the self-assessment to be easy as a technical process; however, there were several factors in the learning setting that made the process challenging, and it was relatively difficult for teachers to describe the workshop activities and process topics in terms of the curriculum. Following the preliminary test, the teachers described activities in more detail and developed new activities that better supported the ideas of the curriculum and the pedagogical innovation process.

Preconditions for a makerspace in CDT education

The second phase of this study considered the results of studies I and II in relation to the learning outcomes, the current workshops, the ways of supporting various learners and the pedagogical innovation process (Table 2). The theoretical views on spaces of making were reviewed as follows:

The learning outcomes illustrated weak product design skills (Hilmola, 2011) and teachers' and pupils' differing views concerning them. In the pilot makerspace, proficient co-teaching supported pupils' different interests. A learning environment with various material technologies gave pupils the opportunity to sense basic workplaces, workstations and workshops as makerspaces with multifaceted opportunities. According to an earlier study on positive and negative achievers and underachievers (Hilmola & Lindfors, 2017; Lindfors & Hilmola, 2016), timely support during pupils' processes is important for enhancing pupils' skills and positive attitudes. In studies I and II, the question no longer concerned designing something to be manufactured by textile or technical work techniques (although teachers struggled with how to face the deep-rooted tradition of division). Instead, there was a problem that needed to be recognised and solved with suitable material technologies, as is typical for makerspace and making culture thinking.

A makerspace that integrates the current workshops of textiles and technical work with digital modelling and fabrication could offer a place to develop shared practices (Study I). The digital application (ESM) added a new dimension to community support, but was also necessary to support assessment and pupils' self-regulation. Advanced use of the ESM application connected the concepts of making to a wider context and opened a discussion from the pupils' own perspective. However, making, manufacturing and material technologies gain more weight in practise than design and problem-solving, not to mention self- and peer-reflection and assessment (Study II). Thus, a makerspace must have places for pupils to share work (e.g. ideation, self and peer assessment, idea testing and prototyping). This also seems to be an aspect of instructional practices (e.g. how teachers nurture pupils' interests and motivation). On this basis, makerspaces can be used in creative ways to shift the focus from material technologies to problem-based design processes that utilise different technologies with shared practices as means and tools to create solutions. Teachers have responsibility for safety; thus, a school makerspace must advance safety in the form of both physical facilities and social construction. An important precondition for a makerspace is a space that facilitates a creative atmosphere as a construction of a safe whole. Pupils work in their basic workplaces, move among workstations and work areas and develop their competencies while designing and engineering their solutions. Since physical safety is regulated by norms, co-teaching and pupils' shared work must be adapted using architectural and constructional solutions.

To support various learners, an optimal makerspace should guide pupils and teachers to find solutions and achieve positive experiences. This means that pupils must have easy access to supplies and materials and use them as libraries for design. Abandoning traditional teaching and giving more support to pupils and learning requires certain preconditions. To fulfil pupils' needs and follow the aims of the curriculum, the core competence model for co-teaching (Jaatinen & Lindfors, 2016) is presented as a solution for pupils' needs. From a makerspace criteria point of view, there is a need for spaces that advance co-teaching and move the focus from teaching to enhancing pupils' holistic processes and exploiting various material technologies and workstations in their processes.

Makerspaces and pedagogical innovation processes cross subject boundaries. The results indicate that the co-teaching teams enhanced pupils' learning activities, as the teachers' work was supported by shared spaces, practices and new tools. Proficient co-teaching promoted pupils' different interests in ways that enhanced the pupils' innovation competencies in pedagogical innovation processes through co-teaching rooted in pupils' needs (Study I, Table 1). The learning environment, which was designed to include a basic workplace, various material technology workstations and wider workshops (e.g. digital fabrication, wood work, sewing, engineering and weaving), was considered a holistic makerspace with well-defined areas of working and paths for moving from one workstation to basic workplaces or other workstations. This approach facilitated pupils' multifaceted opportunities to design and fabricate solutions to important problems and motivating them with proficient co-teaching.

Table 2. What are the characteristics of the learning environment that support innovation learning?

Study I (co-teaching and community)	Study II (pupils' identities and peer collaboration)	Studies I + II (instruction—construction)
1. Learning outcomes: Pupils' motivation and freedom—teachers' timely support for pupils and sense of professional control		
Proficient co-teaching supports pupils' different interests and mindsets, allowed and necessary in pedagogical innovation processes. A learning environment with various material technologies gives pupils an opportunity to see basic workplaces, workstations and workshops as makerspaces with multifaceted opportunities.	Pupil- and class-specific skill profiles illustrate various processes. Observations collected directly from pupils in different work phases serve as a "backup" for teachers. To be a usable tool, the piloted teacher application requires a greater focus on user orientation.	The pupils' freedom is supported by environmental psychological considerations, and the teacher's sense of classroom management. Social versus individual equity is considered.
2. Craft workshops as a makerspace (formal learning environments in CDT education): Redefined basic workplaces—workstations and workshops		
Co-teaching allows different kinds of orientations and helps pupils be seen as makers: from human- and aesthetically oriented learning towards multidisciplinary problem-oriented learning. Proficient co-teaching also requires co-operation.	The development of one's own micro-competencies brings a playful, engaging and motivational dimension to learning and is one tool for calibrating motivation.	Basic workplaces are transformed into workstations and workshops. Craft workshops are good preconditions for developing makerspace thinking. Safety culture deals with values, attitudes, knowledge and skills and depends on pupils' own experience and teachers' supervision.
3. Various kinds of pupils: Spatial support for flow—stimulus, inspiration, and materials in a creative process		
Pupils' different uses of various material technologies challenges basic questions concerning the organisation of teaching and the division of teacher labour. Proficient co-teaching is one solution. The shared professional responsibility arises from the responsibility of ordering small things towards a greater vision of the use of a makerspace.	In a meaningful project, the pupil learns the basic skills just in time. The same basic concepts can be learned in many different ways and workstations (the relationship between concepts in the curriculum map and the keywords, without the mediating classroom activities)	The learning environment equals the design process. Spatial support is provided different learners to support a flow-channel useful for rethinking storage as places to share, stimuli, inspiration libraries and material banks in creative processes.
4. Pedagogical innovation process: Crossing subject boundaries—local autonomy makes participatory concepts possible		
Curricula point out transversal competencies. The wide-ranging nature of primary school class teachers' profession provides an opportunity to emphasise the teachers' involvement in makerspace development.	Advanced use of the ESM application connects the concepts of making to a wider context and opens the discussion from the pupils' own perspective.	Teachers operate between broad pedagogical freedom and responsibility for school reform. This pilot study is one example.

While the teachers defined and improved the curriculum concepts and learning contents for the mobile application (study II), they developed their own understanding of the contents of the pedagogical innovation process. From the pupils' perspective, a key issue was not achieving equality across different material technologies, but securing intensified support for self-regulation and individual needs in various processes. On this basis, a makerspace should be a space and a mental state for cultivating design and innovation, instead of mere production. The co-teaching and pupils' different uses of various material technologies challenged basic questions concerning the organisation of teaching and the division of teacher labour. Shared professional responsibility arose from the responsibility of ordering small things towards a greater vision of the use of a makerspace (study I).

The results suggest eight preconditions of formal CDT makerspace design and construction (Table 2):

1. A makerspace should be a place and a space as a mental, physical and social construction that enhances positive experiences, spatial practices and perceptions. (Table 2, spec. 1.)
2. A makerspace should guide teachers and pupils in a future oriented way in their work as co-operators. (Table 2, spec. 1.)
3. A makerspace should be a safe place that encourages various kinds of solutions based on learning tasks. Pupils should be able to use the CDT workspace in a meaningful way by moving between their workplaces and the workshops both independently and according to the teacher's guidance. (Table 2, spec. 2.)
4. A makerspace should be a learning and working environment equipped with various workstations and material technologies that enhance practical problem-solving. (Table 2, spec. 2.)
5. A makerspace should be a place for co-working and co-design that nurtures ideation and design activities, as well as pupils' self- and peer-assessment. A place where it is possible to recognise one's skills. (Table 2, spec. 3.)
6. A place where it is possible to recognise pupils' different personal characteristics and provide timely support to enhance their innovation competence through several kinds of design problems and material technologies. (Table 2, spec. 3.)
7. A makerspace should facilitate that design and technology education exist in cooperation across subject boundaries. (Table 2, spec. 4.)
8. A makerspace should be a shared place for co-teaching and enhancing pupils' innovation competence. A makerspace should facilitate professional co-teaching that recognises pupils' various needs and enhances their attitudes, abilities and skills in pedagogical innovation processes. (Table 2, spec. 4.)

Discussion

The previous studies dealt with co-teaching mainly in the context of special education (see e.g. Murawski & Lochner 2011). The study I considered co-teaching as a new tool to use in creation of the makerspace that integrated the traditional workshops with digital technologies. The triangulation data (study I) made it possible to understand emerging, advanced and proficient co-teaching in the context of CDT education. It revealed the importance of teacher labour division and support and guidance for pupils. On this basis it would be possible to create a questionnaire to enable the use of quantitative data on co-teaching in CDT education to enlarge a dataset in future studies. Despite the case study nature of the results, the co-teaching approach seems to be a promising way to enhance pupils' innovation competences in formal makerspace context.

The digital application (ESM, study II) offered a new tool for following pupils' learning processes. It offered the required resource on its side and revealed how pupils assessed their work. It made very evident (Figure 5), that there is lack of design and ideation to be connected to pupils' making processes. It also seemed to help teachers in understanding the phases in pupils' processes – even if it was difficult at first for teachers to verbalise the various phases of pupils' processes. On the basis of this pilot experiment and data, ESM seems to support pupils and teachers in assessment and pupils' in their self-regulation. ESM (see e.g. Hektner, Schmidt & Csikszentmihalyi, 2007) opened the discussion from the pupil's own perspective in a new way. The advanced use of the ESM-application (Figure 3d) connected the concepts of pupils' processes more deeply and detailed. It seems that ESM could be used in future studies as a research method to obtain lager datasets, but also as a tool in teachers' and pupils' ordinary work in makerspaces. Talking about the makers, pupils could have also been involved in developing the ESM application as it would have been a more user-oriented approach.

A makerspace for formal education (see e.g. Halverson, & Sheridan, 2014) can be developed in different schools on various bases, depending on the shared view of teachers, pupils, school administrators and designers. As a starting point for practical pedagogical solutions to enhance pupils' holistic processes and innovation competence, a makerspace should follow certain basic pedagogical tenets. For example, involving teachers with broad freedom and autonomy is crucial. When developing makerspaces, we had to develop an entire school organisation and multidisciplinary activity system (see Simola, 2017; Hero, 2019). Curricula are renewed every ten years, so the exploration of better methods is always topical.

The selected research methods supported development well. The piloted Studies I and II as well as integration of the results from makerspace point of view can be viewed as a first round of design research. There are a lot of new research possibilities to identify links and relevance between CDT learning activities from a pupil perspective. As Andreas Schleicher, OECD (2017, p. 3) Director for Education and Skills, stated, "If there has been one lesson learnt about innovating education, it is that teachers, schools and local administrators should not just be involved in the implementation of educational change but they should have a central role in its design". On the basis of the study at hand, we would add that in makerspace creation also pupils should have a central role.

Conclusion

The tendency for makerspace development is both global and local concerning informal and formal settings. Pupils should learn problem solving at schools by developing solutions to problems they define based on meaningful learning tasks. Design and making in formal learning require more empirical research to develop the theory, knowledge and skills necessary to design new kinds of learning environments: makerspaces that support creative problem-solving for problems that do not yet exist. Research seldom asks what kinds of learning environments would best facilitate this outcome.

According to the curriculum for primary and secondary education, persistent and innovative working processes and positive experiences that strengthen self-esteem and bring joy are crucial for CDT

(FNBE, 2016, p. 290). The results imply that the pilot makerspace with professional co-teaching could be one way to transform CDT learning from the tradition of textile and technical work to a teaching and learning approach that facilitates pupils' innovation competence.

Studies of grades seven through nine and different local premises might offer other suggestions for how Finnish comprehensive school can create space for makers. However, the results of this study are relevant, as education policy challenges touch everyone, whether the emphasis is on balancing material technologies, science and technology or some other cultural tension. In a more user-oriented approach, pupils should also be involved in developing the application, since a study with a piloted application is like a first round of design research. There are many possibilities for new research to identify the relevance of and links among activities from a pupil's perspective.

Makerspaces in formal education should enhance pupils' possibilities to design, manufacture, fabricate, test and assess innovative solutions to meaningful problems and challenges. They should also support holistic processes of learning to develop highly usable solutions, including small-scale innovations as learning experiences on a personal level. Teachers consider a good CDT learning environment to consist of appropriate collaboration and division of teacher labour, as well as an environment and tools that support pedagogical innovation processes and pupils' self- and peer-assessment. The future-oriented CDT makerspace can be seen primarily as a "state of mind" that involves a re-evaluation of both teachers' and pupils' current practices. On this basis, the makerspace should be a space and a mental state for cultivating design and innovation, instead of mere production. An important precondition for a makerspace is a space that can facilitate a creative atmosphere and pupils' scaled innovations to construct a safe whole.

Limitations

This case study and development project was carried out in grades one through six in one school in a single Finnish town. Due to the nature of the data, the results are not widely generalisable, though the number of pupils (n = 578) is statistically reasonable to allow for broader conclusions. However, the study gives an example of how to develop CDT learning environments as makerspaces by considering teachers' and pupils' perspectives.

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Children’s Responses to Divergent and Convergent Design Feedback

Alice Schut, Delft University of Technology, The Netherlands

Remke Klapwijk, Delft University of Technology, The Netherlands

Mathieu Gielen, Delft University of Technology, The Netherlands

Marc de Vries, Delft University of Technology, The Netherlands

Abstract

In this paper, we explore the divergent and convergent nature of design feedback and the various responses to this feedback from a group of 24 young novice designers (primary school children age 9-11) taking part in a co-design project. Earlier research emphasizes that feedback can encourage a designer to take divergent as well as convergent paths during their design process (Cardoso, Eris, Badke-schaub, & Aurisicchio, 2014; Yilmaz & Daly, 2014, 2016). Yet our previous research shows, that feedback given to primary school children while designing does not always spark creative thinking (Schut, Klapwijk, Gielen, Van Doorn, & De Vries, 2019). We presume that the responses we found might have been influenced by the type of feedback that preceded them. Therefore, we have elaborated on the results we’ve previously uncovered with an additional analysis of the same case study. This additional analysis shows that divergent feedback given by peers or a client will not necessarily promote divergent thinking processes, whereas convergent feedback will not necessarily promote convergent thinking. Furthermore, responses indicating resistance towards the feedback given were widespread. However, we believe that feedback from clients and peers can still be a fruitful strategy in learning to be creative and in promoting divergent thinking (DT) and convergent thinking (CT) and end with suggestions on how this might be achieved.

Keywords

design feedback, design fixation, convergent thinking, divergent thinking, creativity, D&T education

Introduction

In recent years, creativity is progressively seen as a skill of great value within the context of primary education. Design and technology-related subjects offer great opportunities for children to develop their creative abilities (Lewis, 2005, 2009; Rutland & Barlex, 2008; Thijs, Fisser, & Hoeven van der, 2014; Voogt & Roblin, 2012) and more and more focus is put on the importance of this provision in Design and Technology (Atkinson, 2000; Benson &

Lawson, 2017; Benson & Lunt, 2011; Klapwijk & Holla, 2018; Lewis, 2005). When designing, children are confronted with ill-structured problems, which are open ended in nature and solutions are not defined in advance (Dorst, 2003; Lewis, 2005). This means that no one ‘right’ answer exists and they therefore need to resort to creative thought processes to generate and develop solutions (Lewis, 2009).

Yet behaving creatively does not always come naturally to children. For example, it is known that the occurrence of design fixation – a sort of block in creative thinking processes – can hamper the generation and development of creative solutions by driving the children to think along the path-of-least resistance and leaving them fixated on certain aspects of their design (Luo, 2015; McLellan & Nicholl, 2009; Nicholl & Mclellan, 2007; Schut et al., 2019). It appears that there is a need to help the children identify and understand the obstacles in their creative thinking and help them move forward in their creative process.

It is commonly thought that receiving design feedback from others is one of the factors that can benefit the creative design process greatly (Crilly 2015). Design feedback can help guide the creative thinking processes - divergent and convergent thinking - that are present in a design process. Design feedback can push towards convergence by suggesting evaluation, reflection and decision making. It can also push towards divergence by suggesting the exploration of alternatives. Yet, one may ask if the divergent or convergent nature of the feedback always elicits the expected responses and therefore push towards the intended direction in one’s creative process. Design feedback is expected to teach novice learners insight in their creative processes and design decisions, yet it can also uncover or evoke resistance (Cardella, Buzzanell, Cummings, Tolbert, & Zoltowiski, 2014; Cardoso et al., 2014; Cummings, Tolbert, Zoltowiski, Cardella, & Buzzanell, 2015; Schut et al., 2019).

Our previous study shows that feedback that is given to primary school children while designing does not always spark creative thinking (Schut et al., 2019). In this article, we will therefore look at the same case study in order analyse feedback conversations that take place between the children who are designing, their peers, and the client during the later stages of their design processes. Our goal is to identify the divergent and convergent nature of the design feedback present in the critiquing moments and the various responses of the children to this feedback. This is translated into the following explorative research question: What is the nature of the design feedback that is given by client and classmates and how do the design teams respond to these different types of feedback? We are especially interested in the moments in which the children show resistance to design feedback and hope to uncover how this might relate to the divergent or convergent nature of the feedback.

Divergent and convergent thinking

Designing is an inherently creative activity (Goldschmidt, 2014; Howard, Culley, & Dekoninck, 2008). It requires complex cognitive processes through which a designer explores the problem and solution space (Dorst & Cross, 2001). Two creative thinking processes herein play a central role: divergent thinking (DT) and convergent thinking (CT) (Finke, Ward, & Smith, 1992; Goldschmidt, 2014, 2016; Guilford, 1956, 1962). DT entails the generation of novelty, which is commonly thought to go hand in hand with the ability to see lots of possible answers and interpretations to a problem or issue. CT entails the evaluation and exploration of this novelty, which deals with developing, analysing and selecting the 'best' answer to a problem or issue. Though the continuous alteration between DT and CT creative solutions get generated and developed (Guilford, 1967; Howard-Jones, 2002; Isaksen, Dorval, & Treffinger, 2010; Isaksen & Treffinger, 2004; Mioduser & Kipperman, 2002; Tassoul, 2009).

Yet understanding how and when to best shift between these cycles of thought is not easy, especially for novice designers. Many factors can hamper these creative thought processes. For example, the occurrence of design fixation, known as the blind adherence to a limited set of ideas or problem solution (Jansson & Smith, 1991; Purcell & Gero, 1996), is a known obstacle in young novice learners' design processes (Luo, 2015; Mclellan & Nicholl, 2013; Nicholl & Mclellan, 2007; Schut et al., 2019). Within design education, guidance in navigating this shifting and alternating process is therefore needed. Although this guidance can take different forms, like structured courses, tools and methods, assessment guidelines and coaching (Dannels, Gaffney, & Martin, 2008; McLellan & Nicholl, 2009; Nicholl, 2004; Nicholl & Mclellan, 2007; Tolbert & Daly, 2013), this article focuses on the role of design feedback.

Design feedback

Although little is known in relation to young novice learners in the design setting, feedback interventions are common educational practice in design disciplines at university level to discuss the progress and status of a student's design projects (Dannels, 2005; Oh, Ishizaki, Gross, & Yi-Luen Do, 2013). Usually, there are several feedback interventions integrated in the design process at different stages. In those moments, students get the opportunity to update their instructors, their peers and other stakeholders, such as real or simulated clients and potential users, on their envisioned design and collect feedback. Oh et al. (2013) describe how these conversations are the predominant way through which students acquire expertise from their instructors and other stakeholders. Additionally, it adds the aspect of socializing students into the discipline, which prepares them for the 'real world' (Cummings et al., 2015; Dannels, 2005; Oak, 2000; Oh et al., 2013).

Commonly these interventions are known as 'design reviews' or 'design crits'. Although there are many similarities, and the terms are often used interchangeably, in this paper the focus will specifically be on design crits. Design critiquing is about improvement. This is attained by discussing how well the design addresses the goals and principles that were set beforehand. Within these discussions is not necessarily about getting everyone's approval, like design reviews tend to be (Sater-Black & Iversen, 1994), but about giving options and opinions on how to move forward within the design process. The active conversations can trigger students to reflect on, evaluate and revise their designs (Oh et al., 2013), therefore impacting on divergent or convergent paths they may take in their creative process.

Divergent and convergent design feedback

Design feedback can steer creative thinking processes in divergent or convergent directions. Although feedback can potentially benefit the creative design process (Crilly, 2015), literature shows that it can also evoke less than optimal reactions in novice designers.

For example, Cardella et al. (2014) and Cummings et al. (2015) investigated the different directions design feedback can push towards and linked it to the processes of creating and reducing ambiguity between instructors and university students. They found that instructors who only work on eliminating ambiguity by giving feedback that pushes towards convergent actions through clarification, can provoke students to become defensive and try even harder to convince everyone of the quality of their design (Cardella et al., 2014; Cummings et al., 2015). These types of interactions could inhibit a student's creative thinking, since they will not easily engage in reflective or evaluative thinking about the state of their idea when they feel they have to justify it.

This focus on clarification through convergent feedback by instructors was also observed by others (Cardoso et al., 2014; Daly & Yilmaz, 2015; Yilmaz & Daly, 2014, 2016). In a study on question asking during design reviews, Cardoso et al. (2014) observed that due to this focus by the instructor, the students end up being too descriptive and do not engage in any reflective and evaluative thinking about the design decisions made. Yilmaz and Daly (2014, 2015, 2016) also observed this focus on clarification and decision making and found that instructors from different disciplines all primarily engage in convergent feedback. They note that although this type of convergence is necessary in working towards a design result, it should not be prioritized over the exploration of 'better' solutions or the pursuit of risky ideas. More balance between both types of feedback is therefore encouraged by the authors and the need for divergent feedback is brought forward (Daly & Yilmaz, 2015; Yilmaz & Daly, 2014, 2016).

From these studies, it appears that the primarily convergent design feedback from the instructors is not always met with the expected reactions from the students and does not necessarily facilitate DT or CT. Similarly, our previous study shows that feedback that is given to primary school children while designing does not always spark creative thinking (Schut et al., 2019). Instead, it was found that the children often rejected or ignored the feedback in order to leave the core characteristics of their design ideas intact and unchanged. This fixation on their idea was observed through four uncovered types of response behaviours: 'band-aids', 'already in there', 'question not relevant' and 'it's not possible' (Schut et al., 2019). Since unwanted reactions to feedback have been observed with university students, it is possible that responses of the children have been influenced by the preceding feedback. It could therefore be worthwhile to explore the nature of the feedback preceding these uncovered response behaviours.

A design feedback model

One of the ways in which the nature of design feedback can be uncovered is through the use of Eris' question driven design model (Eris, 2004). Eris perceives design as a question driven process. He therefore created a model that encompasses the types of divergent and convergent questions asked when designing in teams, which is made visible in Figure 1. Use of this model has, for example, provided insight into the types of questions that can spark creative thinking within design processes (Cardoso, Badke-Schaub, & Eris, 2016).

Although the model is intended to analyse the question behaviour of a design team while designing (Cardoso, Badke-Schaub, & Eris, 2016; Eris, 2004), it has also been used to analyse the feedback present in design crits (Cardoso, Eris, Badke-schaub, & Aurisicchio, 2014). It would therefore be interesting to explore the nature of the design feedback present in our case with primary school children and insight this can give in relation to creative thinking.

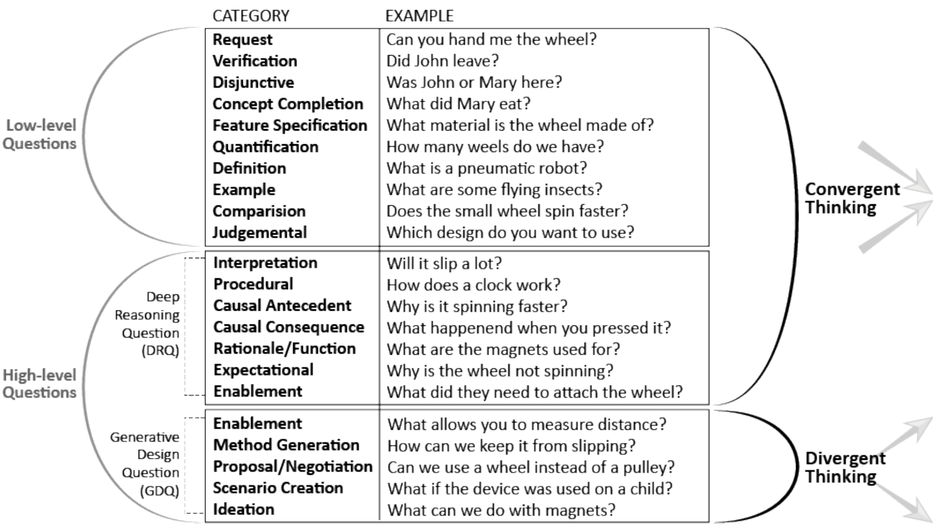

Figure 1. Eris' Question Driven Design Model (Eris, 2004)

Research Design

Participants

The design sessions took place at a primary school in the Netherlands in the area of Zuid-Holland. The selection was based on the school's interest in design and technology education and a wish to experience a guided hands-on design project. The participating school is 'development-focused', meaning that umbrella themes are used to integrate different learning subjects. In this study, one class participated over a period of seven weeks in March and April 2016. The class consisted of 24 children, ranging between 9 and 11 years old. The class was divided into six gender-mixed heterogeneous design teams of four children by the teacher. Although the children had no experience with designing, the teacher stated that the children were used to giving feedback to each other during other subjects in the classroom.

Design problem

The children worked on solving a real-life open-ended design problem. This was made available by the HALO sports academy, which is part of The Hague University of Applied Sciences in the Netherlands. The assignment: "Design a game, lesson or sports equipment for the gymnasium of the future that enables children with different participation motives to be physically active together." An example of different 'participation motives' is a child who enjoys a competitive component during physical activities and plays to win versus a child who enjoys playing together, regardless of winning or losing the game. An experienced teacher from the HALO acted as a client for the children. He introduced the design assignment and was present during several of the design sessions to give feedback on the children's design ideas. He had no specific experience in addressing or teaching primary school children.

Design sessions

Over the course of seven weeks the design teams took part in weekly design sessions of 90 to 120 minutes. In Table 1 an overview of the design sessions and their connection to the design cycle (Figure 2.) known by Dutch primary school teachers and pupils is presented. The design activities were based on tools and methods from the CPS tradition (Isaksen et al., 2010; Tassoul, 2009) and design tools from the Delft Design Guide (van Boeijen, Daalhuizen, Zijlstra and van der Schoor 2013). These methods and tools were transformed for use at primary school level in collaboration with the Science Hub Delft (Wetenschapsknooppunt Zuid-Holland n.d.), which is an organization who develops and researches educational design material for primary schools.

Facilitation

Three facilitators were present during the design sessions to facilitate the teams. Each facilitator was assigned two teams. Two facilitators, the first and second author, had a double role as researchers within the project.

Setting

During the design sessions 2, 3 and 5, the teams were facilitated by their assigned facilitator in separate rooms. Session 1, 4, 6 and 7 took place in a classroom setting during which all teams took part simultaneously.

Table 1. Overview of the design sessions - Session 4 and 7 were selected for in-depth data analysis

Session	Facilitation	Design phase	Activities
1	Classroom facilitation	Exploring & Formulating design problem	- Introduction of the design assignment by the client. - Experiencing different sport preferences and participation motives within the class through group activities led by the client. - Timeline visualization of positive and negative physical education experiences. - Brainstorm to shed first ideas.
2	Separate team facilitation	Exploring & Formulating design problem	- Constructing interview questions. - Practice interview. - Homework: do interviews with other children.
3	Separate team facilitation	Generating & Selecting ideas	- Discussing the interviews. - 3 brainstorm techniques. - Categorization of all ideas. - Idea selection. - Top 4 selection.
4	Classroom facilitation	Generating & Selecting concepts	- Make a small model/first prototype of two ideas. - Feedback on ideas from the client and classmates (1st critiquing moment) - Selection of one idea.
5	Separate team facilitation	Building a prototype	- Make a building plan. - Build a prototype with provided materials. - Make a testing plan.
6	Classroom facilitation	Testing & Optimizing	- Build-up for the test. - Test with other children. - Get feedback from testers. - Think of implications for design.
7	Classroom facilitation	Presenting	- Feedback on designs from the client and classmates (2nd critiquing moment)

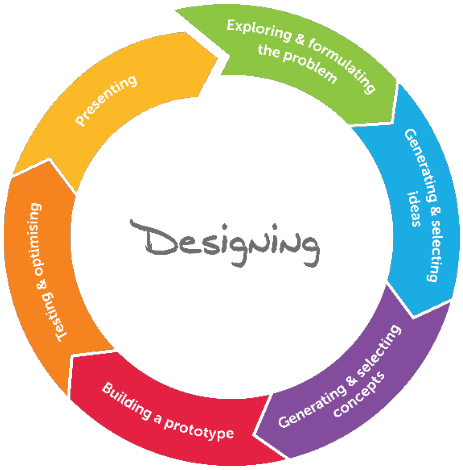

Figure 2. The Design Cycle (Klapwijk & Holla, 2018)

Critiquing moments

During the 4th and 7th sessions the design teams received feedback from their classmates and the client on the state of their design ideas through two design crits. For both critiquing moments the client and children received no specific instruction from the facilitators on how to give feedback. It was expected that the teams would use the feedback that was given to improve their design idea by adjusting and elaborating on its current state. This expectation was communicated to the teams by the client through a short presentation at the start of design session. In this presentation the importance of feedback in relation to idea development was pointed out through the phrase: “Feedback = OK!” and several examples. Additionally, the client pointed out that although sometimes you might feel hurt or attacked by the feedback that is given, it is always meant to help.

The first critiquing moment took place during the 4th design session. At that moment in the design process all design teams had selected one or two initial ideas and constructed corresponding small ‘quick and dirty’ models. Through turn taking each design team had the opportunity to present their design idea, illustrated with the models. After presenting their design idea each team received feedback from the client, as well as from the other design teams (their peers).

The second critiquing moment took place during the 7th design session. All design teams had prepared a short presentation in which they illustrated their final design with drawings or photos of their prototypes. Again, the design teams received feedback from the client and the other design teams (their peers). Since this was the final design session, the focus was not so much on possible future improvements, but more on revealing the final state of the design. This expectation was also communicated to the children by the client.

Data collection and analysis

The seven design sessions were audio and video recorded and the materials that the children produced during the sessions were photographed.

Segments and pairs

To examine which type of feedback and responses occurred together, the feedback and concurrent responses were grouped before coding. Segments were created of consecutive feedback and responses based on the feedback content. Within these segments pairs of feedback and response were formed. When multiple questions and comments were posed in a row, or when multiple answers were given in a row, these would be grouped to form one pair consisting of multiple feedback and response codes. All pairs were coded with the corresponding feedback type codes and response type codes. Additionally, we coded who posed the feedback to the design teams i.e. the client or peers. The qualitative analysis software Atlas.ti was used during the entire analysis process.

Feedback types

To determine the nature of the feedback, Eris's question-driven design model (see Figure 1) was used as our primary lens to analyse the feedback posed by the client and peers (Eris, 2004). The model makes a distinction between two levels of questions: Low-level Questions and High-level Questions. The High-level Questions are divided into Deep Reasoning Questions (DRQs) and Generative Design Questions (GDQs). Low-level questions are mainly information seeking questions and are posed when a questioner for example wants clarification or verification about certain aspects of the design. High-level questions ask for a higher level of reasoning and often entail reflection, evaluation and/or generation. In the model, Low-level Questions and DRQs are classified as convergent. These types of questions are presumed to facilitate convergent thinking processes and share the common premise that a specific answer, or a specific set of answers, exists. GDQs are classified as divergent, since they are presumed to facilitate divergent thinking processes by proposing alternative answers and prompting their generation.

The first author initially coded all the transcribed data, after which consensus and consistency were promoted by routinely discussing the coded data with the second author. Since we were not solely interested in questions, not all instances of feedback could be coded with Eris' model. These particular segments of feedback were therefore coded inductively, which resulted in three new codes: 'Critique', 'Compliment' and 'Direct recommendation'. For the purpose of this study, we added these three codes to Eris' model and classified them as Low-level Comments and part of the convergent category. This adapted model is visualized in figure 3.

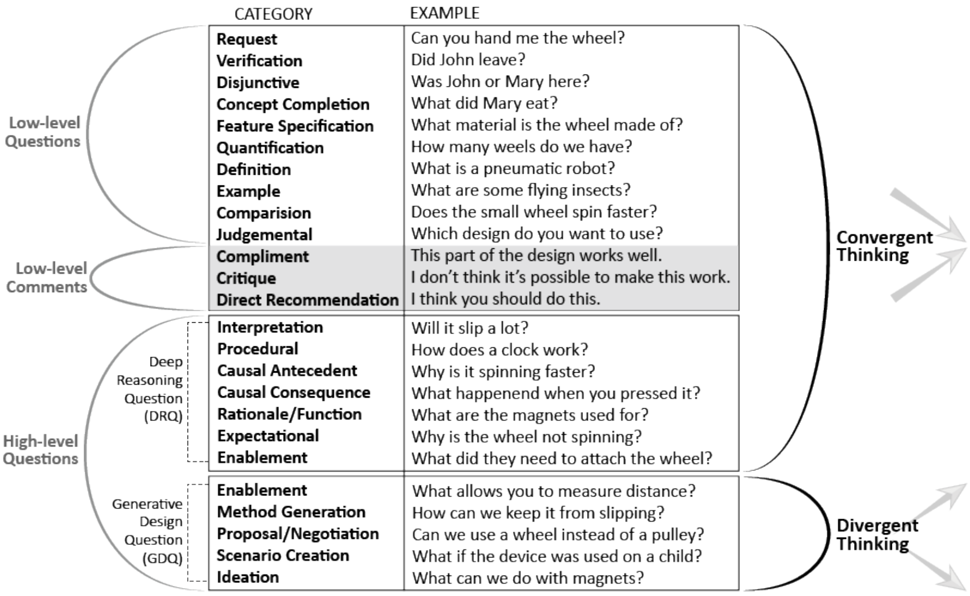

Figure 3. Adapted version of Eris' Question Driven Design Model.

Types of responses

To determine the different types of responses of the design teams, all responses were labelled through open-coding, allowing codes to emerge from the data itself. Four of these response types were previously identified in this particular dataset through open coding, namely 'band-aids', 'already in there', 'question not relevant' and 'it's not possible' (Schut et al., 2019). Afterwards we refined these codes by comparing them to a framework of student response codes created by Cardella et al. (2014) and Cummings et al. (2015). Due to the different context of their studies the conscious decision was made to not use their framework inductively. When comparing the codes uncovered through open coding to the framework of Cardella et al. (2014) and Cummings et al. (2015) we found that several codes overlapped, some could be adopted and a few could be dismissed due to irrelevance to our context. Overlapping codes were merged and the code name from the source that described the response type in most detail was adopted. From this process an improved framework for responses to design feedback in primary design projects emerged, which is made visible in Table 2. Again, the first author initially coded all of the transcribed data, after which consensus and consistency were promoted by routinely discussing the coded data with the second author.

Table 2. Children's responses to design feedback

Code	Description of the behaviour	Source
Band-aids	Adjustments or elaborations to the design idea that do not present a valuable and relevant development and	Open coding, published in Schut et al. (2019)

	leave the flawed core of the design idea intact and unchanged.	
Already in there	Uncovered shortcomings and missing elements within the design idea are dismissed by stating that they have been present within the idea all along when this is not the case.	Open coding, published in Schut et al. (2019)
Question not relevant	Feedback is indicated as not relevant to the design idea.	Open coding, published in Schut et al. (2019)
It's not possible	Proposed adjustments or elaborations are deemed as not feasible without proper evaluation.	Open coding, published in Schut et al. (2019)
Ideation	Coming up with new ideas/exploring new possibilities	Open coding
Confirming	Confirming that what someone states/assumes is correct	Open coding
Insecure	Reaction indicating insecurity about what to answer	Open coding
Show	Physically showing something (part of design/drawing/etc)	Open coding
Ask	Clarifying questions	Cardella et al. (2014) / Cummings et al. (2015)
Restate	Student restates the information from the person providing the feedback	Cardella et al. (2014) / Cummings et al. (2015)
Acknowledge	Indication of active listening	Cardella et al. (2014) / Cummings et al. (2015)
Agree	"Ok", "I will do that"	Cardella et al. (2014) / Cummings et al. (2015)
Report	Explaining a feature or the design	Cardella et al. (2014) / Cummings et al. (2015)
Silence (non-verbal)	No reaction present	Cardella et al. (2014) / Cummings et al. (2015)
Nodding (non-verbal)	Physical response to any type of feedback	Cardella et al. (2014) / Cummings et al. (2015)

Results

The following sections introduce the occurrence of the different types of feedback and responses throughout both critiquing moments. Specifically, we concentrate our efforts towards discussing the responses that indicate a form of resistance towards design feedback and expose their relationship to the nature of the feedback types and additional feedback properties.

Types of feedback

Figure 3 gives an overview of the occurrence of the different types of feedback during the first and second critiquing moment. In both critiquing moments convergent as well as divergent feedback is posed by the client as well as the peers. Overall, the first critiquing moment contained more instances of feedback than in the second. In this first critiquing moment the client posed more feedback than the peers, especially low-level questions, comments and GDQs. In the second critiquing moment the peers posed more feedback than the client. What is remarkable is the relatively high amount of DRQs asked by the peers during this critiquing moment.

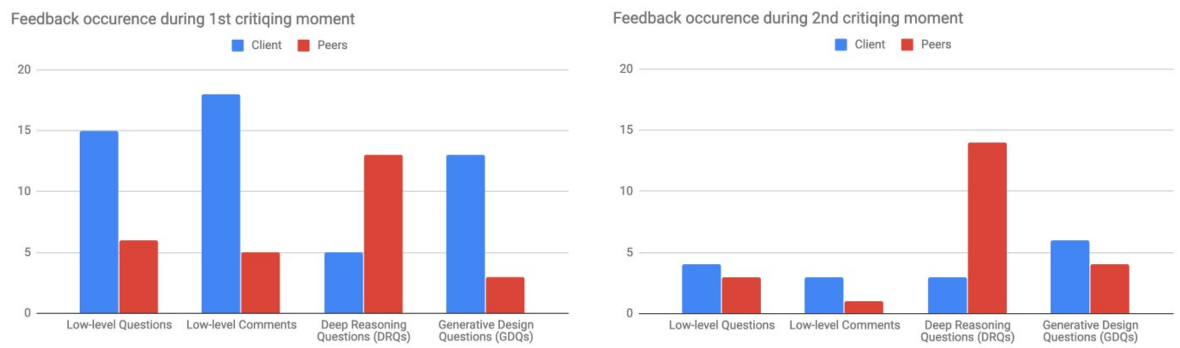

Figure 4. Occurrence of the different types of feedback posed by client and peers during the 1st and 2nd critiquing moments.

Convergent feedback

Overall *convergent* feedback was most prominent during both critiquing moments. When looking closer at the different types of *convergent* feedback, we see that the client mostly engaged in low-level questions and comments, while the peers took a leading role in posing Deep Reasoning Questions (DRQs).

Low-level questions were generally posed by the client to clarify or verify certain aspects of the design idea. For example:

> *Client: What are the game rules?*
>
> *Client: Ok, so if I understand correctly there is a video game attached to it?*
>
> *Client: So, you are moving in the game and on the screen?*

Since the client took a leading role in both critiquing moments and was generally the first to provide feedback to the design teams, this could explain why most low-level questions were posed by the client. The low-level comments that were posed by the client mainly consisted of compliments. Often these compliments were interwoven with other types of feedback. For example:

> *Client: You did choose a really nice topic. Something that everybody will find cool. And that was also sort of my assignment right, creating something that everybody will find cool. [compliment (low-level comment)] Yet, what is really new about it? [Causal Antecedent (DRQ)] What makes this different? [Rational (DRQ)]*

> *Client: I think it's really cool! [compliment (low-level comment)] I envision the gym of the future maybe without all that equipment [proposal (GDQ)]. That there is nothing in the gym, only those beamers and a really cool game that we can project. [ideation (GDQ)]*

In both examples the client starts with a compliment, after which he directly continues with expressing a concern or posing a suggestion.

Even though the peers also posed a few low-level questions and comments, the great majority of their feedback consisted of DRQs. More than half of all feedback that was given by the peers consisted of this type of feedback. The high-level questions they posed were concerned with how the design came to be, how it exactly works and why it works that way. For example:

> *Peer: Well, how can you for example climb that tree?*

> *Peer: Most of the equipment is not very high, so how can you then hide well?*

> *Peer: I don't think a player is able to slide on their knees the entire time. Right?*

In the DRQs above, several concerns are expressed about the designs. By posing these questions the peers ask the design teams to reflect and evaluate their design.

Divergent feedback

Divergent feedback, in the form of Generative Design Questions (GDQs), was present in both critiquing moments. Yet a clear spike in its occurrence was observed in the first critiquing moment, caused by the client. Through divergent feedback he appeared to persuade the design teams to explore alternative features or possible new additions to the design. For example:

> *Client: I am searching for a way to customize it for different players. How could we do that?*

> *Client: So maybe, when using a camera, you [a player] could think 'well, I'm not someone that is able to run fast, so I stay far from the catcher'. And someone who is very good (in running fast), they maybe need something to provoke the catcher a bit?*

Types of responses

The type of responses that followed the different instances of feedback varied throughout the critiquing moments. The occurrence of many of the responses appears incidental, making it difficult to discover distinct patterns. However, there was a group of responses that took a prominent position in both critiquing moments. Together, the 'band-aids', 'already in there', 'question not relevant' and 'it's not possible' made up about half of the responses in both critiquing moments. Through these responses the design teams showed resistance towards the design feedback posed to them. In the next section we present the observed feedback and an overarching pattern preceding these four types of responses. From now on we will refer to these four types of responses as 'resistance responses'.

Feedback preceding the four resistance response behaviours

Convergent feedback

The resistance responses were predominantly preceded by convergent feedback, especially by DRQs posed by classmates. Through these DRQs the classmates often revealed to the design team how they expected certain mechanisms in the design idea to function incorrectly. The following 'no handball included' example illustrates this. In all examples 'designer' plus a number refers to members of a design team.

> **No handball included**
>
> *Peer: If you for example throw a ball during handball,*
>
> *then the computer can never know how fast you throw. Because he can also not…*
>
> *Designer1: But we don't offer handball.*
>
> *Peer: Okay. Then soccer, if you then kick the ball then you don't know how fast you will kick?*
>
> *Client: Well, the computer would be able to measures that. You can make that happen.*
>
> *Designer2: Yes, there are machines that can measure how fast it goes.*

Here the expectation of the classmate is that the computer will never be able to measure the speed of a ball thrown within the game. First the design team tries to parry the question by focussing on the sport used in the example, which they state is not part of their idea. This behaviour enables the team to ignore the question and show that their idea still 'works'. The peer then repeats the expectation, prompting the client to step in and contradict the expectation of the classmate. This help is quickly embraced by the team. DRQs generally ask for reflection and evaluation of the design idea, which can ultimately help to develop and improve it. Yet this behaviour was not observed here. The first reaction of the team to feedback of the peer was to parry it, showing little intention to evaluate the feedback and possibly using it to improve their idea. This behaviour could have been promoted by the peer sharing expectations about the idea without any explanation towards the team as to what these assumptions are based on. A second example showcases another instance in which a peer poses a DRQ, yet does not communicate the expectations and assumptions about the design idea clearly and directly.

No friends needed

Peer: How can you do this game with friends?

Designer: Well. You don't have to do it with two people, you can also do it alone

Peer: Okay…

The peer's question stems from the design question given by the client, which focusses on children being active together. One of the children from the design team answered that the game can be played alone, implying that no other players are needed. This left the peer a bit puzzled. Here, the peer expects the design idea to not fulfil a certain wish of the client, namely: stimulating playing together. Yet this expectation is not communicated directly by referring back to the design problem and the unfulfilled design criterion. Again, the first reaction of the design team is to parry the question, instead of taking it as an opportunity to reflect and evaluate.

Divergent feedback

There were also instances in which the four resistance responses were preceded by *divergent* feedback in the form of GDQs, which were mainly posed by the client. In those cases, the client often proposed multiple new alternatives for certain features or completely new additions to the design idea. The following example from the dialogue showcases how one of the design teams reacts to the *divergent* feedback from the client.

New proposals

Client: What might be nice is something you can see in some playgrounds.

That you get points if you hit something. You know?

Designer: Yes, this game is that you can shoot and then you get points.

Client: Yes. And that could be from two sides this way. Right?

Maybe the computer can control and move this, or that you move it yourself.

Designer: If you stand there the sticks will fall and then you can get them really fast.

Client: Yes, nice. Or maybe this goal can turn around and

that you think of a game in which the goal moves around all the time.

That will keep making the game more difficult.

Designer: [silence...] Maybe… [end conversation]

The client starts with proposing a new addition to the game. The design team reacts by stating that his proposed addition is already present in the idea. The client then continues with a stream of several new additions, showcasing different directions in which his proposal could be manifested in the game. The dialogue then ends with the team showing little enthusiasm towards the proposed additions of the client.

Although the feedback of the client can be classified as *divergent*, it does not appear to spark any new DT processes with the design team. This could be due to the stream of additions the client proposes, which he thinks will make their idea better, without checking with the team how they view these additions in relation to their idea. All the proposed additions appear to stem from the client's expectation that the game needs to get more difficult over time, but this is not mentioned explicitly. Furthermore, the client assumes that the current state of the design idea does not yet fulfil this assumption. Yet this is not communicated clearly, therefore keeping the team in the dark about the client's true intentions for the majority of the dialogue. Although other reasons may exist, this lack in transparency may have caused the design team to be less open to the new additions.

Discussion

Divergent & convergent design feedback

Our results show that with no guidance on how to give design feedback, the client and peers both pose divergent as well as convergent feedback to the design teams. Yet overall, convergent feedback was considerately more prominent in both critiquing moments. This result has similarities with previous studies that also found convergent feedback to occur more frequently (Cardella et al., 2014; Cardoso et al., 2014; Cummings et al., 2015; Yilmaz & Daly, 2014, 2016). We observed that the client posed the majority of convergent feedback through low-level comments and questions, concerned mainly with clarifying the designs of the teams. This focus on clarification by the client has similarities to previous studies, where instructors were observed to also have this tendency (Cardella et al., 2014; Cardoso et al., 2014; Cummings et al., 2015).

Although few instances of high-level convergent feedback were found with the client, more than half of the feedback posed by the peers consisted of high-level convergent DRQs. By posing these questions the peers ask the design teams to reflect and evaluate their past, present and future design decisions. This is quite remarkable and suggest that more research on this phenomenon is needed. One explanation could be that because they were participating in the same design sessions as the design teams presenting, certain design choices made by the teams were more striking to the peers than to the client. Additionally, the teacher noted that the children were used to giving feedback during other subjects, although we have no information on the nature of this feedback. Next to this, we speculate that the client might not have known how to pose these types of reflective and evaluative questions to that age group, therefore abstaining from it. Cardoso et al. (2014) found the instructor in their study to also abstain from DRQs in a university context, which could point to a more general difficulty in posing these types of questions.

Even though overall convergent feedback was more prominent, divergent feedback was also present in both critiquing moments. The client was the one primarily engaging in divergent feedback in the form of GDQs. Additionally, there was a spike of divergent feedback during the first critiquing moment. We speculate that this could be due to the unfinished state of the design ideas during the first critiquing moment and assume that the client tried to encourage the teams in developing their ideas by posing GDQs.

Reactions to the design feedback

The results on the occurrence of the different type of responses showcase how the convergent or divergent nature of the feedback does not necessary guarantee the start of the corresponding thinking processes within the design teams. Around half of all responses consisted of one of the four resistance responses, which stagnated the divergent and convergent thinking processes of the design teams. In those instances, the convergent feedback, especially DRQs, did not lead the design teams to reflect or evaluate their design. Instead the design teams appeared to become defensive and tried to prove the quality of their design, which is similar to results found by others in the context of higher education (Cardella et al., 2014; Cardoso et al., 2014; Cummings et al., 2015). Additionally, the occurrence of resistance responses also pointed out how divergent feedback did not always spark new ideation processes. It appears that convergent or divergent feedback alone is not enough to guarantee the start of new divergent or convergent processes with the children.

Possible contributing factors

The resistance the design teams exhibited to the design feedback given by the client and peers hampered their creative thinking processes. We believe there are several factors that could have contributed to this high occurrence of resistance responses by the teams. Firstly, we speculate that the high occurrence of convergent feedback may have limited the initiation of creative thinking processes within the design teams. High occurrence of convergent feedback is thought to hamper exploratory thinking and risk taking, which are both essential within creative processes (Tolbert & Daly, 2013; Yilmaz & Daly, 2016). Although convergent thinking is essential in working towards a final design, more balance between divergent and convergent feedback could prove promising in creating better and more creative designs.

Coupled with this, we expect that (implicit) expectations and assumptions about the design ideas, that we found present within the convergent and divergent feedback, hindered the initiation of both DT and CT thinking processes. Interpretive challenges in feedback are known to cause communication problems for students and instructors (Sadler, 2010). Due to the implicit nature of the expectations and assumptions, there was an absence of mutual understanding between the design teams, the client and peers about the (sub)problems present in the designs. Since the teams did in general not use the feedback to subject their design to any critical evaluation (CT) in order to detect these (sub)problems, there was no need to generate new ideas (DT) to elaborate or adjust the design. Critical evaluation appears to not come ‘naturally’ to the children, a notion that is supported by research done by Blom and Bogaers (2018) in the field of Linkography with young novice designers (age 13-14 years).

Furthermore, the parrying of feedback by the design teams suggests that they might have felt a high level of attachment to their design ideas. This could have made it difficult for them to decide to accept or reject the feedback, since their abilities to objectively consider the feedback might have been impaired. Literature shows that high levels of ownership can create feelings of loss when confronted by suggestions for change, making people less likely to fully adopt the given feedback (Baer & Brown 2012). Yet, we must note, that in itself, feelings of ownership can also have a positive impact on developing promising ideas of which their potential is not immediately recognized. A designer has to develop the skills to be able to balance between remaining open to possible flaws within the design ideas, yet also persistent in developing a promising idea despite receiving negative feedback (Crilly, 2015; Csikszentmihalyi, 1999).

Ultimately, it appears that there is a need for guidance on deciding what to do with each piece of feedback; (partly) accept or (partly) reject. The development of critical thinking skills are needed in order to objectively explore the feedback before accepting or rejecting it. Novice designers must learn to suppress the tendency to immediately reject criticism, and 'temporarily accept' it in order to explore its merit.

Conclusion

Earlier research emphasizes that feedback has the ability to encourage a designer to take DT as well as CT paths during their design process (Cardoso et al. 2014; Yilmaz & Daly 2014, 2016). Nevertheless, our results show that feedback on design ideas does not necessarily help young novice designers (children age 9-11) to engage in divergent and convergent thinking processes. Our study shows that divergent feedback will not necessarily promote divergent thinking processes and convergent feedback will not necessarily promote convergent thinking. Resistance responses were widespread. The novice designers frequently rejected feedback immediately instead of accepting it temporarily in order to explore its merit. This led to stagnation of divergent and convergent thinking processes within the teams, resulting in a lack of critical reflection and a loss of openness which hampered the creative process. We point to the assumptions and expectations of clients and peers that were only implicitly present in the feedback on the design ideas as one of the factors sparking this resistance in design teams. We therefore suggest (1) the use of concrete convergent feedback followed by (2) divergent feedback in order to regain openness and spark new creative thinking processes.

We believe that feedback from clients and peers can still be a fruitful strategy in learning to be creative and to apply DT and CT thinking. However, all parties involved – teachers, clients and pupils - need to learn to give and receive sound feedback. Feedback conversations should be constructed carefully, as they are sensitive and filled with fragile egos, sensitive identities and insecure learning processes (Dannels, 2011; Goldschmidt, Hochman, & Dafni, 2010; William, 2018). What is being said and by whom, and the reactions that follow, create a complex minefield in which all participants need to learn to navigate. We suggest that, design feedback needs to be concrete and should clearly explain any expectations and assumptions the feedback giver might have about the design in order to reach a mutual understanding. When a mutual understanding is reached about the (sub) problems within the designs, there is room to regain openness and use divergent feedback questions in order to spark new DT processes. Additionally, the development of critical thinking skills could help young novice designers to objectively explore the feedback before accepting or rejecting it.

Limitations

This article has some limitations due to the focus on the responses directly after the feedback was given. It is possible that in some instances, the feedback may have instigated the concurrent divergent or convergent thought processes at a later stage within the teams.

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Editorial

Continuing a methodological approaches thread

Kay Stables, Goldsmiths, University of London, UK

Lyndon Buck, Buckinghamshire New University, UK

Donal Canty and Niall Seery, the guest editors in this issue of the journal, have taken particular decisions in choosing the articles that, amongst other things, demonstrated the breadth of and relationships between research agendas that have developed over the many years that the PATT conferences have brought together an international community of researchers in design and technology education. Their choices have included fore-fronting early career researchers and research agendas emerging from the 2018 PATT conference. But their choices have also illustrated a breadth in research methodologies that have been presented through the articles included. This illustration of breadth continues through the articles in this issue that have been submitted through the regular system. Guest editors curate their selections. By definition general submission create a more haphazard collection. We have four such submissions in this issue, two reporting on higher education, two on schools education, one from Finland, one from Ireland and England, one from Turkey and one from the USA. All four are individual and fascinating accounts of research. By chance, they provide four distinctly different methodological approaches and, in preparing this editorial, this difference appeared as a collective contribution, illustrating a richness of methodologies to be considered, modified and exploited by others.

Seeing links and exploiting them is paving the way for future guest editions – some prompted by the editors, some emerging from the community. We are delighted to include the guested contribution in this issue and would be very happy to receive proposals for future guest contributors. Please get in touch if this interests you.

But now to the remaining articles.

In *Using a Hybrid Pedagogical Method in Undergraduate Interior Design Education*, Suchismita Bhattacharjee (University of Oklahoma, Norman, USA), presents research exploring a flipped classroom pedagogical approach. The research was undertaken with second year undergraduate students in an interior construction class in three consecutive years, each year taking a different approach (traditional, flipped, then a hybrid of the two). The motivation behind the research was to explore ways of providing opportunities for greater amounts of time for students to apply knowledge through hands on creative activity. The focus and content of the course was similar across all three years researched – just the pedagogy changed. Data was collected via a pre and post test was completed by the students and student assessment grades were also utilised. In addition, student evaluations were collected. The article provides understanding of the detail of the three pedagogic approaches taken and fascinating insights into the variation across the three years of students. The overarching conclusion was that the hybrid approach was the most successful. A useful account is also provided of what students found to be the most critical success factors and how the approach could provide a way of transitioning more successfully to a flipped approach.

In *Evaluating Adopt-ability of Open Source Tools for Problem Solving in Specific Design Tasks in Industrial Design Education,* Onder Erkarslan and Zeynep Aykul (Izmir Institute of Technology, Turkey), report on research that explored the ways and extent to which undergraduate industrial design students made use of Open Source Tools (OST) in their design learning. They begin by providing insight into a broad range of OST that have potential to eliminate design 'obstacles' in Industrial Design Education but indicate that their effectiveness in this context needs greater exploration. They posed research questions such as how and why they should be used, what stages of designing they could support. How and why students should engage with open source communities and how students responded to using OST when designing. In a study involving students from three different Turkish universities, they made use of both quantitative and qualitative approaches, first gathering survey data to investigate whether OST can help students and the level of awareness and knowledge students held. This was followed by two case studies of students using such tools when designing. The first project involved students re-designing studio projects using OST. The second involved group projects where their designing was undertaken in a way that simulated an open source community. The article provides a useful and broad range of examples from student projects. Amongst a fascinating set of findings, a stand-out insight was student's initial inability to see a need for open source – they couldn't see the value of collaborating, as their experience of education was about their own attainment. Once working in the collaborative, simulated community their perspective changed from that of an individual student to focusing more on preparing to take a place in their profession.

In *The roles of material prototyping in collaborative design process at an elementary schoo*l, attention is turned to young children's education. Varpu Yrjönsuuri, Kaiju Kangas, Kai Hakkarainen and Pirita Seitamaa-Hakkarainen, (University of Helsinki, Finland), report on research into maker-centred design learning with 10-11 year olds working collaboratively to prototype ideas in open ended design projects. The authors were interested in prototypes as aids for thinking, as social mediators in collaborative designing and as material constraints and inspiration. The research was undertaken with 75 children working in small teams, across 11 weekly sessions of 90 minutes. The children were supported by one craft teacher and three class teachers, researchers and other experts, such as parents and a professional inventor. The aim was to co-invent and prototype novel ideas for everyday problems. Data was collected by video, analysed at macro, intermediate and micro levels. The macro level analysed the flow of design activities coding verbal actions, embodied actions, non-task related actions and collaboration, mapped as 'process rugs' that illustrated beautifully the interweaving of types of design activities. Intermediate analysis focused on significant events and micro analysis was highly detailed coding of 16 significant events. The many findings illustrate clear insights into the ways that collaborative prototyping aided thinking in ideation processes and also as ideas were refined. Evidence of the ways that prototypes act as social mediators was also created, showing how verbalisation and discussion were supported and illustrating ways that collaboration was enacted. Material constraints became apparent in practicalities of prototyping but at the same time it was clear that interacting with materials was also impacting on the children's understanding of materials and their properties and becoming both excited and frustrated by these. In overarching conclusions, the authors draw attention to the pedagogical and theoretical implications of the study, including the extent to which the learners focus was increasingly on creating the prototype, not on developing their design ideas and how this could potentially be mitigated by clear goals and constraints that could focus attention on the design challenge.

Finally, in *Considering the relationship between research and practice in technology education: A perspective on future research endeavours***,** Niall Seery, **(**Athlone Institute of Technology, Ireland**),** Richard Kimbell, **(**Goldsmiths, University of London, UK**),** Jeffrey Buckley, (Athlone Institute of Technology, Ireland & KTH, Stockholm Sweden) and Joseph Phelan, (University of Nebraska, Lincoln, USA) focus on developments in researching design and technology education over the last 30 years, using the history of two related research groups as a core narrative. They begin by providing an overview of current situations in design and technology education in schools, from an international perspective and of how, variously, traditional vocational and craft oriented education has evolved over time towards approaches that vary between design and technological literacy, capability and perspective. Difference has caused confusion along with critique of a perceived lack of explicit epistemological boundary – seen as both a negative and a positive. The article supports a need and focus for future research agendas by presenting the evolution of research conducted by two major research groups in the international community – TERU (Technology Education Research Unit) founded in 1990 and TERG (Technology Education Research Group) founded in 2010. An overview of the history of the research of the two groups is outlined, along with how they became collaborators, developing and extending understanding of teaching, learning and assessment research in technology education. The article also draws on related research from the international community and indicates how the nature of the more than 30 years of research has shifted in terms of both issues of concern and methods of research that collectively provide a legacy to scaffold future research agendas across the community.

As one of the editors of this journal, Kay has to declare an interest in this article – not as one of the authors but as one of the founder members of TERU.

As an endnote to this editorial we should mention that this issue contains no reflection piece or book review – normal service will be resumed in the next Issue!

Using a Hybrid Pedagogical Method in Undergraduate Interior Design Education

Suchismita Bhattacharjee, University of Oklahoma, Norman, USA

Abstract

A flipped-classroom pedagogical method has been adopted by some educators over several past decades both knowingly and unknowingly. In this pedagogical method, the traditional classroom lecture and homework settings are flipped. Students are required to watch short video lectures as homework while the regular class sessions are devoted to in class activities. Flipped-classroom methods have been used as a pedagogical approach in different classroom environments from k-12 to college or university level class settings. There are several evidences of this pedagogical approach being adopted in both social science and pure science class settings. In this study, the author discusses the effectiveness of a flipped classroom method as a successful pedagogical approach for interior design students in achieving educational objectives.

The author investigated a flipped classroom pedagogical method by adopting it in a sophomore level Interior Construction class. The choice to implement a flipped classroom method in this class was due to a rigid lecture and lab component which required the students to work on projects based on the lecture materials covered in the class. The course was taught by the same instructor covering similar content in three consecutive years; using a traditional pedagogical method, a flipped classroom pedagogical method and using a hybrid approach of traditional method and flipped classroom method. A one-way ANOVA results of the student test scores suggested a significant effect of the pedagogical method on student performances for the three classes. Results suggest a flipped classroom as an effective way forward when combined with traditional method as adopted under the hybrid approach.

Keywords

flipped classroom, active learning, instructional method, interior design education

Introduction

The current millennial students pursuing a degree in any higher education establishment have grown up in a digital world. They are more connected to technology specifically with the use of computers in their everyday activities. Coupled with advanced information technologies (IT), the presence of media rich environments have pushed the millennials (ages 18 through 22) to be experiential learners (Oblinger, 2004). Inclination towards learning by doing in contrast to the traditional approach of learning by listening reflects the preference of the millennials towards a collaborative learning experience supported by technology that offers clear learning objectives, enhanced engagement, and is based on experiential learning (Oblinger, 2004).

It is the onus of the instructors to create an effective learning environment for the millennial generation students thus keeping them active and engaged in classroom. The instructors need to expand their repertoire of technology-based teaching methods, that are more engaging than the traditional approaches of using lectures, text based slides, or assignments (Lo, 2010). In a quest to offer an improved learning environment, the author adopted a hybrid of both a flipped classroom teaching method and a traditional teaching method in an Interior Design lab class serving the Interior Design major students. The goal of this paper is to discuss the effectiveness of a hybrid classroom teaching method as a pedagogical approach for interior design students in achieving educational objectives. The paper provides a brief review of literature related to common pedagogical strategies that have been adopted in Interior Design education and how a flipped classroom teaching method can be implemented in addition to replacing the traditional type of interior design in higher education. The author further explains as an example how a flipped classroom teaching method was incorporated in an Interior Construction class and its benefits and challenges.

Pedagogical Methods common in Interior Design Education

Interior Design (ID) has gained wide acceptance as a profession over the last forty years, but has been in existence for more than a century. The origin of ID can be traced back to the art of decorating (Martin & Guerin, 2006). Since then the profession has evolved into a specialized area of expertise that requires several years of education and experience. Today there are approximately 167 schools in the United States offering a Bachelor degree in Interior Design that are recognized by Council of Interior Design Accreditation (CIDA). The growth of Interior Design programs in the United States has created an environment where the teaching and learning processes adopted have become an important consideration. With the growth of Interior Design as an academic discipline, universities have strived to employ effective teaching strategies and classroom environments to replicate the dynamic atmosphere typically faced by the design personnel in their professional lives.

The learning outcomes that are highly valued by design students and professionals include creativity, problem solving skills, decision making skills, communication skills, teambuilding, and leadership skills (Biggs, 2011). Design programs are expected to design and offer courses that can nurture the aforementioned attributes in students. Design educators today have started exploring various pedagogical methods that can be adopted for enhanced student learning (Ö. O. Demirbaş, 2001; O. O. Demirbaş & Demirkan, 2003; Kvan & Jia, 2005; Uluoğlu, 2000). Demibraş and Demirkan (2007) suggest that design students should learn by experiencing, reflecting, thinking and doing in the process of finding solutions to assigned design problems.

Pedagogical strategies used in design education identify a number of essential components that can facilitate the desired learning outcomes. These components emphasize the student-centred active learning strategies that can be in the form of (1) problem-based teaching, (2) collaborative teaching, (3) game and simulation based teaching, (4) case study-based teaching, (5) involving students in projects and presentations, and (6) peer-tutoring (Kember & McNaught, 2007). Most of these active learning techniques require enhanced involvement of the students in comparison to that of the traditional approaches. Additionally, to nurture ability the educators should create an environment for the students to apply their knowledge. However, this sometimes poses an impediment for the students given the limited class time available to the educator and the students. Thus, the instructors are often in a quest for innovative pedagogical methods to maximize the usage of available class time.

The students prefer to be engaged in critical, multidisciplinary problem-solving activities as compared to mere acquisition of facts on specific subject areas (Schofield & Davidson, 2002). The roles of the instructors have evolved from being repositories of knowledge to being facilitators who can set up projects, arrange for access to appropriate resources, and provide support that can help students succeed. This approach of experiential learning is getting more preference than the traditional approach that is based on fact acquisition and recollection. As a result, instructors across the globe are trying to improvise their pedagogical methods to involve more information and communication technologies (Bransford & Cocking, 2000).

To maximize the utilization of class time and promote experiential learning, educators are identifying ways to use technology in classroom education (Means, Olson, & Ruskus, 1995; Means, Penuel, & Padilla, 2001; Sandholtz, 1997; Schofield & Davidson, 2002).

Flipped Classroom Teaching Method

A flipped classroom teaching method has been adopted by some educators over several past decades both knowingly and unknowingly (Abeysekera & Dawson, 2015). In this pedagogical method, the traditional classroom lecture and homework settings are flipped (Milman, 2012). Students are required to watch short video lectures as homework while the regular class sessions are devoted to solve assignments or work on projects. A flipped classroom teaching method has been used as a pedagogical approach in different classroom environments such as high school and middle school classroom settings to college or university level class settings. There are several evidences of this pedagogical approach being adopted in both social science and pure science class settings (Bergmann & Sams, 2014; Berrett, 2012; Ihm, Choi, & Roh, 2017; Njie-Carr et al., 2017; Smith, 2013; Teo, Tan, Yan, Teo, & Yeo, 2014).

Several educators over the last decade have identified the various benefits of flipped classroom teaching method when implemented in different streams of education (Fulton, 2012; Ruddick, 2012; Simkins & Maier, 2010; Strayer, 2012; Zappe, Leicht, Messner, Litzinger, & Lee, 2009).

As mentioned by Tucker (2012), a flipped classroom helps the students to utilize the class time to solve problems, advance concepts, and engage in collaborative learning instead of just one-way lectures. Lage et al. (2000) experimentally implemented flipped classrooms for an introductory level Economics course. Although they spent about 2 hours per topic to create videotaped lectures and digital slide presentations with voiceovers, yet they found that preparation time was significantly reduced after the initial groundwork was completed. As they reported, the major benefit of using a flipped classroom teaching method was the increased class time devoted to "an economics experiment or lab that corresponded to the topic being covered." As identified by Roehl et al. (2013) another benefit of using a flipped classroom is the less time spent on developing lectures, which could be devoted to creating innovative activities that “deepen concepts and increase students’ knowledge retention”. As concluded by Roehl, Reddy and Shannon (2013) a flipped classroom is specifically beneficial for topics where class lectures are just direct instruction, as it can now be covered as a homework assignment. Several other benefits of flipped classroom identified by Fulton (2012) are the opportunity for students to learn at their own pace; in-class activities which provide the teacher with a better understanding of student difficulties and learning styles; increased level of student achievement; interest and engagement; and more effective use of class time. In a traditional classroom setting the instructors are not aware of student understanding level until an assignment or test in graded. However, a flipped classroom provides the educators with an opportunity for awareness of student performance, due to increased interaction (Chickering & Gamson, 1987). Additionally, in a flipped classroom it is easier to address students’ absences due to illness or University priority athletic or extra-curricular activities (Roehl et al., 2013).

In addition to all the benefits listed earlier, flipped classroom has its own limitations. A flipped classroom is not applicable for all streams of education (Roehl et al., 2013). Based on a study conducted by Strayer (2007, 2012), a flipped classroom teaching method did not prove to be beneficial for teaching an introductory statistics course. Depending on the technology used to convey the lecture materials to the students, the course content might not be flexible enough for impromptu changes. Though with the advent of new technologies, educators might be able to better make adjustments to the already recorded lectures (Prensky, 2010).

In this type of pedagogical approach, the students are responsible for their individual learning experience (Tucker, 2012). Sometimes it might be difficult for the educators to conduct in-class assignments if the students are not well prepared. For this reason, it is important for the instructor to include a component of application of information during in-class activities. As mentioned by Tucker (2012), the benefits of this pedagogical approach is more evident when students start asking questions and think more deeply about the content as the year progresses.

Application of Flipped Classroom Teaching Method in Design Education

The author was investigating pedagogical methods for a sophomore level Interior Construction lecture/lab class in an Interior Design education program. Based on the creative nature of the design field and the strong need for application of knowledge, the author wanted to utilize the majority of the class time, applying the knowledge by designing and creating. After lecturing on a certain topic in class, there was never enough class time left for students to apply the knowledge through hands-on creative activity. The presence of both Interior Design major and minor students in the class caused diversity in the ability of the students to understand and apply the course content on interior design projects. Due to this diversity and varying levels of understanding of the content, the class time was often not being used effectively as the instructor had to invest additional time to help students individually while keeping other students waiting.

The author investigated flipped classroom teaching method to implement it in the above mentioned Interior Construction class. The choice to implement flipped classroom in this class was due to a rigid time consuming lecture and lab component and the need to apply the knowledge through hands-on creative activity. The above mentioned Interior Construction course was taught by the same instructor covering similar content in three consecutive years; 1st time using traditional pedagogical method, 2nd time flipped classroom method, and 3rd time using a hybrid method of traditional method and flipped classroom method.

The purpose of this study was to assess the effectiveness of each pedagogical method over each other in a design based education system.

Description of activities

The contents of the three-sophomore level Interior Construction classes during the three consecutive years were similar, but the delivery methods were structured differently. The course content included power-point based lectures, construction process videos, and activities related to the design, drawing and construction of interior building elements as shown in Figure 1- 3. The different topics covered during this course were interior partition walls, flooring, ceiling, doors, stairs & ramps, building systems coordination, codes knowledge as related to occupancy, means of egress, fire protection, and accessibility requirements. The class projects, not only required the students to design and develop construction drawings for partition wall, floors, ceiling systems, stairs etc., but also required the students to apply building codes and identify design solutions for provided situations.

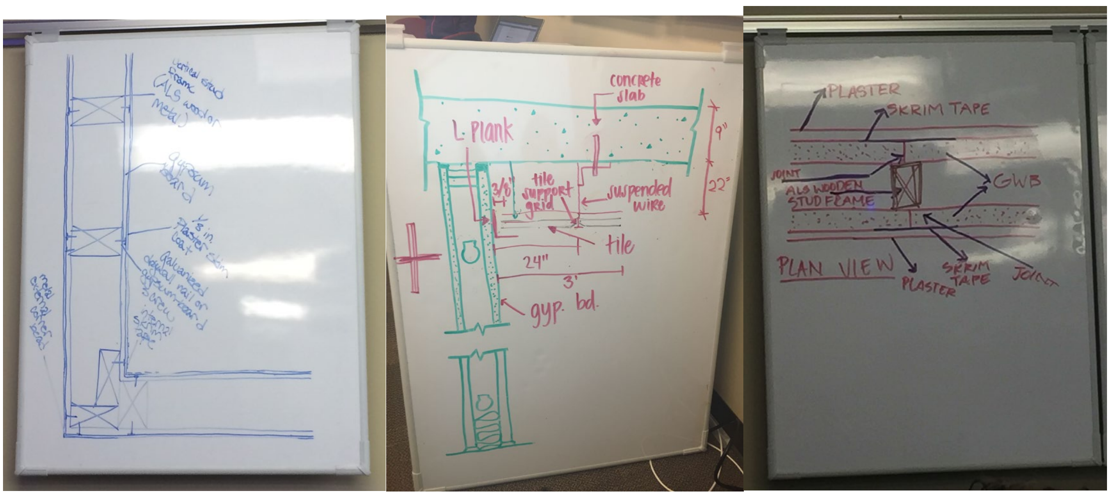

Figure 1: In-class Construction Drawing Assignments

Figure 2: Stairs Model

Figure 3: Room Section Model

Figure 4: Kitchen Cabinet Model

Using Traditional Method

For the first year, similar to any other traditional pedagogical method, the majority of the class time was spent on reviewing lectures. Though the students were required to review the book chapter on that particular topic before the class lecture, the instructor noticed that several of the students came unprepared to class and were entirely dependent on the instructor to explain the content to them during the class. This student behaviour in addition to the diversity in the ability of the students to understand and apply the course content delayed the allotted class lecture time, thus reducing the class time that could be used for working on hands-on creative activity to apply the knowledge covered in classes. The students had to complete most of the hands-on projects as homework assignments. This was often problematic as the students did not have the individual support they needed when applying the knowledge, they had just learned. Students were also provided with a short 10 questions quiz after each day lecture on the topic covered during that class.

Using Flipped Classroom Teaching Method

For the second year, unlike the traditional teaching method, the flipped classroom teaching method was adopted for the same sophomore level interior construction class. The students were required to review lectures and watch construction process videos as homework and the entire class time was used to work on individual or team hands-on activities which provided the student the opportunity to apply the knowledge. Students were provided with a short 10 questions quiz every class based on the topic of the lecture and the video reviewed. The use of daily quizzes appeared to be a strong motivator for students to review lectures and watch the construction process videos before class. Although this pedagogical method helped a few students, several students complained about their inability to understand the course content without face to face interaction with the instructor. They were thus not able to adequately apply the content knowledge in the in-class projects. According to these students, they were not able to provide their best output on the projects as they did not have a clear understanding of the content before they started working on the project.

Using Hybrid Method of Traditional and Flipped Classroom

For the third year, based on the feedback received from the previous year's students about the application of the flipped classroom teaching method, the instructor revised the content delivery plan and adopted a hybrid pedagogical method incorporating both traditional and flipped-classroom methods. Similar to the flipped classroom teaching method, the students were required to review the lecture and read the book chapter on the content as homework. Instead of devoting the entire class time to hands-on creative activities, the instructor allotted class time for in-class discussions requiring all students to participate. Students were also given a short 10 questions quiz on the topic after class discussion and their application of the knowledge before hands-on activities. Having grades for participating in the in-class discussions increased student participation, thus forcing students to review content ahead of time and also providing opportunities for the students to have a clear understanding of the contents before they started working on the projects for the later part of the class periods.

Data Collection

In an effort to gather data that would help analyse the effectiveness of different adopted pedagogical methods, a paper based questionnaire was developed to conduct pre and post-test among the three classes (traditional teaching method, flipped classroom teaching method and hybrid method). A pre and post-test method of data collection was used and proved to be successful to analyse the effectiveness of courses in various academic disciplines (Hake, 2007). The pre-test was used to assess student knowledge about the Interior Construction subject matter. The pre-test and post-test questionnaire consisted of 10 questions to measure the students level of knowledge about the subject matter. Students we given the same 10 questions as post-test at the end of the semester to test their level of knowledge about the subject matter.

In addition to the above mentioned pre and post-test the author recorded the grades of the students' projects and quizzes for all topics covered to have a better understanding of the student performance.

A mid-semester and end-of-semester student course evaluation was used to measure the confidence in their abilities to solve design problems and answer quiz questions on the topics taught, understand the effectiveness of the instructional materials and course structure, and the effectiveness of the instructor. The course evaluation was used by the instructor to have a better understanding of student satisfaction about the course content and pedagogical approach. The questions were divided into two sections. The first section consisted of questions related to course content, and the second section consisted of questions related to pedagogical approach adopted for content delivery. For the mid-semester evaluation, the author identified the questions based on the study's key constructs of interest. Once the first draft of the evaluation instrument was developed, the instrument was reviewed by research measurement expert to ascertain the content validity of the items and technical quality. Feedback from the research measurement expert was incorporated into the final draft of the evaluation instrument.

The quantitative data (pre-test post-test score) was analysed using one-way ANOVA to check for any significant differences between the three classes. The qualitative data was analysed by performing a theme analysis to look for patterns that could provide explanations of what was happening in the three classes. The section below provides the description of the differences in student learning outcomes based on the adoption of the different pedagogical methods.

Results & Analysis

Comparison of Pre-test and Post-test Scores

A one-way between subjects ANOVA was conducted using the pre-test scores to check for any significant difference between the entry level knowledge for the students of all three classes. There was no significant difference in the entry level knowledge at $p<0.05$ between the student of the three classes (traditional, flipped and hybrid) [$F(2,42) = 0.56$, $p=0.578$].

A one-way between subject ANOVA result of the post-test scores suggested a significant effect of pedagogical method on student performance at $p<0.05$ level in the three classes [$F(2,42) = 3.52$, $p=0.038$]. Further, post hoc comparisons using the Tukey HSD test indicated that the mean student post-test score of traditional method ($M=23.5$, $SD=2.61$) was significantly different than hybrid method ($M= 25.64$, $SD=2.11$). However, the mean student post-test score of just flipped classroom method ($M=24.56$, $SD=1.56$) did not significantly differ from traditional or the hybrid method.

Taken together, these results suggest that just adopting flipped classroom teaching method has no significant effect on student performance. However, the results suggest that a flipped classroom is an effective way when combined with the traditional method as adopted under the hybrid class system.

Qualitative Comparison of Student Evaluation Responses

The effectiveness of the course materials and the instructors teaching method was compared using the students' responses to the mid-semester and end of the semester student course evaluations.

Effectiveness of Instructional Videos and Lecture Materials as a Tool for Learning

When asked about the effectiveness of the instructional videos and lecture materials, students of the traditional method and flipped classroom method classes responded that the course content which included the lectures and the construction process videos provided either a satisfactory, good or excellent opportunity for learning as shown in Table 1. The student of the hybrid method class mentioned that the course content was either excellent or good. Although the mean score for the effectiveness of instructional materials were less for the flipped classroom than the traditional classroom, the Coefficient of Variation (CV) was maximum for the flipped classroom method. Though a large percentage of students in the flipped classroom method found the instructional videos and lecture materials to be helpful, as mentioned previously several students complained about their inability to understand the course content without face to face interaction with the instructor and they were not able to adequately apply the content knowledge in the in-class projects. This problem was well addressed during the hybrid method since class time was allotted for discussion on specific topics requiring all students to participate, followed by a short 10 questions quiz on the topic of discussion. The mandatory quiz forced the students to review the instructional materials as homework before attending class. As seen in Table 1 below, the hybrid method class received a higher mean score with reduced CV.

Table 1: Effectiveness of Instructional Videos and Lecture Materials as a Tool for learning

	Traditional Method	Flipped Classroom Method	Hybrid Method
% of Student selecting Excellent (5)	73.08	55.56	70.00
% of Student selecting Good (4)	7.69	22.22	30.00
% of Student selecting Satisfactory (3)	19.23	22.22	0
% of Student selecting Fair (2)	0	0	0
% of Student selecting Poor (1)	0	0	0
Mean Score	4.54	4.33	4.70
Std. Div. (SD)	0.81	0.86	0.48
Coeff. of Variation (CV)	0.18	0.20	0.10

Effectiveness of Projects and Assignments as Tool for Learning

When asked about the effectiveness of Projects and Assignments to provide good opportunities for learning, the responses varied greatly among the three classes. In the traditional method where the class time was devoted to lectures and all projects and assignments were assigned as 'take home tasks', the students did not find much value for learning. The mean score was higher for the hybrid method and flipped classroom method as most of the class time was devoted to the projects and assignments. The projects and assignments were more effective as a tool for learning since the students understood the concepts better which was evident through the difference in pre-test and post-test scores.

Table 2: Effectiveness of Projects and Assistants as Tool for Learning

	Traditional Method	Flipped Classroom Method	Hybrid Method
% of Student selecting Excellent (5)	46.15	41.67	60.00
% of Student selecting Good (4)	38.46	58.33	30.00
% of Student selecting Satisfactory (3)	11.54	0	10.00
% of Student selecting Fair (2)	3.85	0	0
% of Student selecting Poor (1)	0	0	0
Mean Score	4.27	4.42	4.50
Std. Div. (SD)	0.83	0.51	0.71
Coeff. of Variation (CV)	0.19	0.12	0.16

Effectiveness for the use of class time

When asked about how effectively class time was used for either lecture or working on assignments, the students in the hybrid lecture method classroom seemed to be most satisfied with the use of class time followed by the traditional method. Instructor observed that the flipped classroom method students often found it difficult to work on assignments without clear knowledge about the subject matter, when entire class period was devoted towards in-class assignment and projects. It was noticed that when asked to review the lecture slides as homework, the students either did not review the slide or did not understand the subject matter well while reviewing the slides. Thus, without clear knowledge of the subject matter the students were not able to effectively use the class time to work on assigned projects. However, for hybrid class when a portion of the class time was devoted to in-class discussion on the subject matter, the instructor observed that the students have a better understanding of the subject matter thus helping them further to work on the projects or assignments.

Table 3: Effectiveness of the use of class time

	Traditional Method	Flipped Classroom Method	Hybrid Method
% of Student selecting Excellent (5)	52.0	33.33	60.00
% of Student selecting Good (4)	36.0	25.0	30.00
% of Student selecting Satisfactory (3)	12.0	41.67	10.00
% of Student selecting Fair (2)	0	0	0
% of Student selecting Poor (1)	0	0	0
Mean Score	4.4	3.92	4.49
Std. Div. (SD)	0.71	0.90	0.68
Coeff. of Variation (CV)	0.16	0.23	0.15

Clarity of the Instructions for Projects and Assignment

Though the same instructional materials were provided for the projects and assignments for all the three classes, the students of the traditional method classroom found the instructional materials to be less clear than the hybrid or the flipped classroom. Since the students were only introduced to the subject matter during class and they were required to complete all the projects and assignments as homework, they often did not understand the instructions well, thus affecting their overall performance on the projects and assignments.

Table 4: Clear Instructions for Projects and Assignments

	Traditional Method	Flipped Classroom Method	Hybrid Method
% of Student selecting Excellent (5)	33.33	46.15	50.00
% of Student selecting Good (4)	25	38.46	40.00
% of Student selecting Satisfactory (3)	8.33	7.69	0
% of Student selecting Fair (2)	25	3.85	10.00
% of Student selecting Poor (1)	8.33	3.85	0
Mean Score	3.5	4.19	4.3
Std. Div. (SD)	1.44	1.02	0.94
Coeff. of Variation (CV)	0.41	0.24	0.22

Stimulation of Interest on the Subject Matter

When asked if the instructor and the instructional method were able to stimulate interest in the subject matter, the students of the hybrid method classroom had the highest mean score. While working on the assignments or projects, the instructor observed that the students in the hybrid method class had a better understanding of the subject matter and were more attentive.

Table 5: Simulation of Interest on Subject Matter

	Traditional Method	Flipped Classroom Method	Hybrid Method
% of Student selecting Excellent (5)	33.33	61.54	80.00
% of Student selecting Good (4)	50	26.92	20.00
% of Student selecting Satisfactory (3)	8.33	3.85	0
% of Student selecting Fair (2)	8.33	7.69	0
% of Student selecting Poor (1)	0	0	0
Mean Score	4.08	4.42	4.8
Std. Div. (SD)	0.90	0.90	0.42

Coeff. of Variation (CV)	0.22	0.20	0.09

Benefits & Challenges of Flipped Classroom

An analysis of the pre-test and the post-test scores indicated that the students from the hybrid classroom were more successful in their abilities to confidently answer problems. The Instructor noticed that for the flipped classroom though many students performed better on assignments and test, several students complained about their struggle to fit into this new pedagogical approach. The main struggle the students faced during the flipped classroom was learning the content as homework all by themselves. As indicated by the students during in-class discussion they often did not understand the content from the lecture notes and construction videos only and hence required explanation on certain topics. Upon further discussion on the topic, the instructor noticed that students were also reluctant to change their personal learning strategies they have been using for years. Such adjustments are often difficult to cope up within such short period of time. But when the same flipped classroom was combined with traditional method (i.e. lectures as homework and in-class discussion for clarity) the students felt more confident about the subject matter. Additionally, since a lot of the class time was also devoted towards the projects and assignments, the students felt more confident with the application of the course content.

Limitations

Even though the Interior Construction course was taught by the same instructor covering same content every year, the study had its unique limitations. The cohort of students for all the three years were different, but the pre-test scores were analysed to assess the variance in student knowledge about the Interior Construction subject matter.

Conclusion

Higher educational institutes are faced with a constant pressure to improve learning experiences for students by engaging them more. The flipped classroom can be the strategy to capture the attention of the millennial students by providing clear learning objectives, helping with retention of knowledge, improve communication skills, and increase problem solving skills. With so many advantages, a flipped classroom teaching method has been suggested to be the path for the future education (Bergmann & Sams, 2014; Berrett, 2012; Ihm et al., 2017; Smith, 2013).

However, in the authors experience the hybrid classroom method proved to be more successful than a flipped classroom teaching method. It proved to be one possible step towards a more customized learning environment. Such a hybrid method could be implemented fairly easily for other Interior Design courses with sufficient technical support to facilitate delivery of prerecorded lectures to students. Based on the students’ feedback it was evident that in-class discussions and activities, in addition to the review of lectures and construction videos were a critical motivating factor that likely contributed towards better student performance on the post-test. The hybrid method allowed the author more class time to emphasize/reiterate important concepts and make the students work on problem solving exercises. The author made sure the students were provided the necessary background information (not limited to only lectures and videos) before they were assigned the problems. One of the many benefits of this hybrid pedagogical method was the opportunity of personalized learning for students, where they were allowed to move at their own pace through the instructional materials when reviewing them as homework.

Future pedagogical methods for design education, however, must give priority to the learner centric approach which requires rethinking of the traditional method studio based and lecture based teaching. While the educators have the flexibility to implement innovative pedagogical methods, they are still restricted by the current requirements of the educational system, which requires that all students complete the learning objectives of the course in the same amount of time (typically one semester). As suggested by (Watson & Reigeluth, 2008) a time-based system should be replaced by the learner centric system that allows students to work at their own pace as needed in order to master a topic. The hybrid pedagogical method adopted by the author is an example of a strategy that works for both the current educational systems and also promotes student centred learning system.

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Evaluating Adopt-ability of Open Source Tools for Problem Solving in Specific Design Tasks in Industrial Design Education

Onder Erkarslan, Izmir Institute of Technology, Turkey

Zeynep Aykul, Izmir Institute of Technology, Turkey

Abstract

The purpose of the study was to evaluate the adoptability of Open Source Tools (OST) as a learning strategy in undergraduate Industrial Design (ID) education. OST has the potential for students to overcome certain difficulties in specific tasks, such as design presentation, design research, design decision, concept generation and design documentation. In this study, both quantitative and qualitative methodologies are used to develop the research. As the first step of the research, quantitative methodology is employed, using a survey method to collect data from students. The survey investigates industrial product design students' perceptions of difficult tasks and their reasons, as well as their awareness of OST. In the second phase of the study, qualitative methodology is followed to acquire feedback on the proposal regarding Open Source (OS) use in an ID studio course using case studies. The simulation follows qualitative methodology, using primarily observations and obtaining verbal feedback. The results indicated that students were willing to adopt OST as an effective design tool and to overcome difficulties in the design process.

Keywords

educational technology; open source tools; adoptability; problem solving; industrial design education

Introduction

The basis of openness is accessibility which means people can access to view, modify and use something. The Internet gave momentum to Open Design (OD) and its other elements like Open Innovation (OI), Open Source (OS) hardware, software, etc. because it made sharing possible from anywhere and also made it easier for students to access proprietary software, applications and the tools. Open Source Culture is the creative practice of appropriation and free sharing of found and created content including collage, found footage film, music, and appropriation art. In OS, the main function is collaborative effort, where people can use, improve and distribute software within the community. Anyone can contribute to a source with his or her knowledge and experience. Each of OI, OS, and OD refer to one of the steps of accessibility which are: to view, modify, and use (Avital, 2011).

“OD is a catchall term for various on- and off-line design and making activities. It can be used to describe a type of design process that allows for (is open to) the participation of anybody (novice or professional) in the collaborative development of something”. (Tooze, Baurley, Phillips, Smith, Foote & Silve, 2014, p. 538).

Open Source Tools (OST) are software tools that are freely available without a commercial license. Many different kinds of OST allow developers and others to do certain things in programming, as well as maintain technologies or other types of technology tasks. OST offer an easy, cheap, and practical way to express design ideas. In addition to ID contribution to OST and the evolution of these tools in favour of ID, OST can assist with design processes in terms of easiness, low cost, and practicality. OST are valuable tools for both the design education community and the OD practitioner community because of their multidisciplinary nature. Previous practices in ID were mostly concerned with making the products given to designers look and function better. ID as a field has stopped approaching design as the act of making objects and reinterpreted the responsibility of the designer to fulfil the needs of people (Sanders & Stappers, 2011).

ID education involves a combination of the visual arts disciplines and technology, utilizing problem-solving and communication skills (NASAD, 2008). Specific NASAD standards and guidelines for ID programs in the United States comprise 30-35% of the total program; supportive course in design, related technologies, and the visual arts, 25- 30%; studies in art and design history, 10-15%; and general studies and electives, 25-30% (NASAD, 2011-2012). Students learn to sketch, model, design, and visually communicate in studio courses taught by ID faculty and industry experts. The courses aim to help ID students gain specific skills in design presentation, design decision, design research, concept generation and design documentation (Chen, 2015). In OS usage, users are also developers, so the technology evolves by and for those that use it. There are many tools and platforms that are based on the OS philosophy. Besides, the more industrial designers use OS the more they improve the tools to make them more convenient for their own needs. Furthermore, the issues of today’s world are more complex than can be solved by only designing the form and function of a product. Programming, interaction, and human cognition are skills that industrial designers need as much as they need drawing, forming or moulding skills (Norman, 2010). In the example of Virginia Tech, Norwegian University of Science, Technology and Eindhoven University of Technology and Delft University of Technology, ID students use Arduino to move their design from sketches through to their real functions of wearable and pervasive computing products. (Alsos, 2015; Martin, Kim, Forsyth, McNair, Coupey & Dorsa, 2013). ID students can use OS both for their immediate and future problems since these tools help them in education as well as in industry.

OD and practices have been largely investigated in the literature: *Co-creation* (Galvagno & Dalli, 2014; Mobbs & Hawkridge; 2010; Vargo & Lusch, 2008); *Co-design* (Steen, Manschot & De Koning, 2011; Sanders & Stappers, 2008); *Open innovation* (Hossain, Islam, Sayeed, 2016; Torres & Ibarra, 2015); *Open design solution* (Tooze & Baurley et al., 2014); *Open design contribution* (Tooze et al., 2014; Mari, 2002; Kadushin, 2012; Smith, 2008); *Open Innovation practices* (Mobbs & Hawkridge; 2010); and *Open design process* (Tooze et al., 2014). The education of today is not suitable to create the multidisciplinary environment necessary to solve current complex problems. New skills are needed instead of disciplinary skills (Alsos, 2015; Martin et al., 2013; Yeh, Lo, Huang, & Fan, 2007; Auer, Juntunen & Ojala, 2011). OST can be used not only for software development but also in many areas, such as mechanical, electrical engineering, business, forensic, space studies, etc., and they are used in engineering education since they offer reliability, customization, innovation, collaboration and low cost (Scholz, Juang, 2015; Armesto et al., 2015; Benavides, 2011; Austin, 2007). OD can operate in the commercial sphere and generate economic value. Young designers are indeed pursuing OD activities, using open software and contributing to building OD communities (Menichinelli & Bianchini et al., 2017).

Reasons for using OST in many areas of education include preventing the limitations caused by the high cost of educational software and products and avoiding closed source tools that prohibit modifying them to follow technological and innovative changes in the area. OST can be used as an effective tool to eliminate design obstacles in the ID studio, but its efficacy has not yet been fully evaluated. Our objectives were as follows: 1) to introduce the OS concept to ID students and make them use these tools in their design processes, 2) to make students contribute to open culture and engage students with the OS Community, and 3) to evaluate the effectiveness of OST during the students' design process compared to the re-designing their previous projects in a traditional ID studio course.

To attain the objectives and solve the defined problems, following research questions were posed:

1 How and why should ID students be introduced to OS ideas?
2 Which stage of the design process can be supported by OST?
3 What was the students' approach to using OST in their design process?
4 How and why can design students engage with OST and the community?
5 What were the results of OST experienced by ID students in their design process?

Methods and findings

ID departments in Turkey receive undergraduate students according to the national university placement exam, which is held by the Student Selection and Placement Centre. In a three-stage sampling research process, three ID schools were selected according to their entrance exam results, accessibility and student number. Based on admission scores, the first three universities in the 2016-2017 term were the Middle East Technical University (METU), Istanbul Technical University (ITU), and TOBB University of Economics and Technology (TOBB). However, TOBB was excluded from sampling since only one student was registered in the design studio there in that year. Instead, Izmir University of Economics (IEU), the fourth university on the list, was included in a face to face survey. Questionnaires were sent to ITU and METU via mail and were also conducted directly (Table 1).

	First Questionnaire							Second Questionnaire						
Universities	Number of participants	Student year				Gender %		Number of participants	Student year				Gender	
		1st	2nd	3rd	4th	Female	Male		1st	2nd	3rd	4th	Female	Male
METU	44	-	-	37	7	62	48	47	-	-	27	20	66	44
ITU	32	-	8	15	9	74	26	65	-	28	26	11	76	24
IEU	71	-	19	34	18	80	20	61	-	18	27	16	79	21
	Age Average		20.2	21.8	22.4					20.3	21.6	22.6		
SUB-TOTAL	140	-	27	86	34	72	28	173	-	46	80	47	77	23

Table 1. Sample characteristics.

Phases of Research Methodology

The questionnaires aim to determine whether OST can help ID students with any tasks in the design studio course and to measure ID students' knowledge and practice level for OS. Data were collected from ID students through the 1st questionnaire (Appendix 1), and difficulties in the design process, according to the data gathered, were analysed. Data analysis of the questionnaire was performed, and a same brief lecture was designed to introduce the open philosophy and its tools to ID students by Zeynep Aykul. According to data gathered in the feedback session through the 2nd questionnaire (Appendix 2), two pilot studies were performed to determine the best environment in which to observe students' use of OST. Simulation of Open Source Community (OSC) was performed in the Introduction to Design Thinking Course in the ID Department at ITU in the fall semester of 2016-2017. Assignments were evaluated through a SWOT analysis and questionnaire of the evaluation of the simulation of OSC. Student presentations on all aspects of their experience with the OSC and adoption of OST were evaluated through observation and an Evaluation Form for Simulation of OSC (Appendix 3). In the final week of the open source session, students presented all their experience with the open source community and tools in the jury. Students were willing to use OST in their ID studio projects, and their general opinion is that they would be useful (Aykul, 2016, p. 111-146).

Preliminary Research

1st questionnaire for evaluation of ID students

The questionnaire has four sections: personal information, tasks in the ID studio course and difficulty level, reasons for difficulty, and awareness of open source. In the first section, three questions ask for information on name and surname, e-mail address, school, year. Tasks in ID studio course and the difficulty level form another section, with a question that contains 20 items on a 5-degree Likert scale. These items are named T1 to T20 (Table 2).

Code	*Task*	*Activity in Open source web platform*
T1	Data collection and analysis	Source
T2	Presentation of data (how they can be used in design)	Indirect
T3	Understanding theme of project	Indirect
T4	Understanding requirements of projects	Indirect
T5	Generating sufficient ideas	Source
T6	Changing and developing ideas	Sharing, Source
T7	Expressing the concept quickly and correctly	Contribution, Source
T8	Finding inspiration	Source
T9	Generating form and style according to user's need	Source
T10	Finding reference knowledge	Source
T11	Decision skills	Sharing
T12	Evaluation criteria	Indirect
T13	Meeting lecturer's expectations	Indirect
T14	Digital modelling	Source
T15	Physical Modelling	Source
T16	Preparing presentation poster	Indirect
T17	Organization of presentation	Indirect
T18	Affording presentation budget	Source
T19	Delivering project in due time	Source, Contribution
T20	Affording overall budget for project	Source

Table 2. Tasks in ID Studio Course and Their Codes.

Students should accomplish several tasks when creating a design. The tasks are design research, concept generation, design decision, design presentation, and design documentation. These five categories comprise 34 sub-tasks. In the questionnaire 20 of the 34 sub tasks are chosen, for the purpose of eliminating possible misinterpretations by students through excluding similar subtasks. The next section also includes one question that aims to learn the reasons for students' difficulties in these tasks. Reasons can be classified as experience; technical knowledge, such as ergonomics, material, etc.; budget; time; technical support, such as help in the workshop, equipment, etc.; relevant courses; lecturer; and classmates. There were 16 reasons under three categories to examine in Chen's study: The first was personal problems included *capability, thinking, techniques and skills, experiences, personality, aesthetic, knowledge, and other issues*. The second was resource problems; *money (cost), time, technical support, equipment and tools, and related courses*. The third was interaction and communication problems occurred with *instructor and peers* (Chen, 2015). However, in this research, students were asked about only 8 of them. The personal category was excluded for it did not serve the purpose of evaluating the adoptability of OST to overcome certain difficulties in the specific task in ID studio course, but rather it was used to explore learning problems. The reasons are named R1 to R8 in a list to be found in Table 3.

Code	*Reasons for Difficulties*
R1	Experience
R2	Technical Knowledge
R3	Budget
R4	Time
R5	Technical Support
R6	Relevant Courses
R7	Lecturer
R8	Classmates

Table 3. Codes and reasons for difficulties.

The following section measures the awareness of ID students about open source. There are 3 questions that ask whether the respondent has ever heard the term 'open source'; about knowledge regarding specific OST, including Arduino, Raspberry Pi, Rasbian, OpenIoT, BugLabs, Makemagazine, RepRap, Lasersaur, GrabCAD, Thingiverse, Blender, Freecad, Inkspace, Gimp, and Scribus; and, lastly, if they used one of these tools or another OST in their design studio course project, as well as whether they think such tools are useful.

Data collection and analysis of questionnaires

For the 1^{st} questionnaire, there were five different difficulty ratings: 'It is not difficult', 'A little difficult', 'Somewhat difficult', 'Difficult' and 'Very difficult'. Each rate was assigned a score from 1 to 5, respectively, to determine their total difficulty rate for each task in the design studio course. Then, the analysis of questionnaire focused on tasks that had total rates higher than the average ratio to analyse the reasons for this difficulty. DR(Tx) difficulty rate for each task from T1 to T20. 140 students answered the first questionnaire, so each student's rating for each task summed up and is showed in the graph.

$$\sum_{1}^{140} DR\ / = DR(T1)$$

To find the average difficulty rate, each task's difficulty rate was summed up and divided into 20.

$$\left(\sum_{T1}^{T20} DR\right) / = Average\ (T1)$$

As seen in Figure 1, some tasks were above the average difficulty rate of 382,55 such as meeting lecturer’s expectations (T13), affording budget (T18, T20), time management (T19), expressing concepts correctly and quickly (T7), finding inspiration (T8), decision skills (T11), and generating sufficient ideas (T5), with the task of meeting lecturer’s expectation supported indirectly by OST. For instance, OST made a contribution to Data Collection with source, so this made an impact on Data Presentation indirectly. As the element of OST, the open source tools could support T5, T8 T18, and T20. By sharing their designs, ID students could overcome difficulties in T11. T7 and T19 could be overcome by both contribution and source of OST (Figure 1).

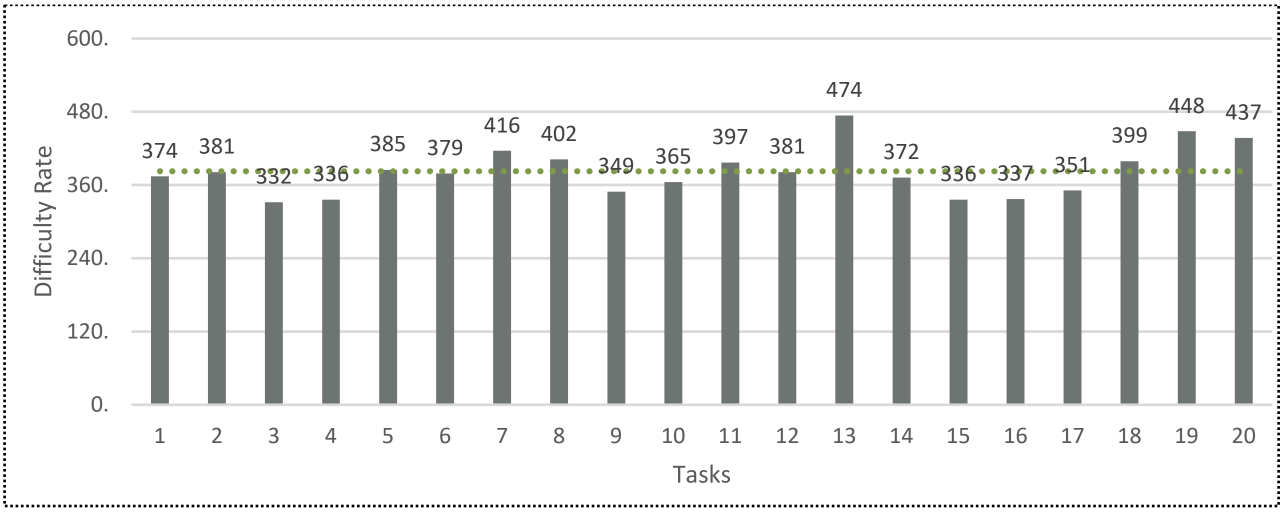


Figure 1. Difficulty rates and task analysis of question 1.

In the following portion of the questionnaire (Appendix 1), reasons for these difficulties were analysed. These reasons were experience, technical knowledge, budget, time, technical support, relevant courses, lecturer, and classmates (Chen, 2015). According to the collected data, a lack of experience, technical knowledge, and technical support were the most common reasons behind the difficulties in design processes. As seen in Figure 2, total of 141 students answered Question 6 (Appendix 1). 106 of students knew the term “Open Source” and 35 of them did not. There was an obvious difference between these two groups when the data were examined in total. However, 4th-year students from METU and 2nd- and 3rd-year students from ITU participated in the research as small groups, so their data did not provide information that could be correctly generalized. Nevertheless, there was approximately the same ratio of 75%

to 25% in nearly every data group, except those with limited participation and the 2nd-year students from IUE.

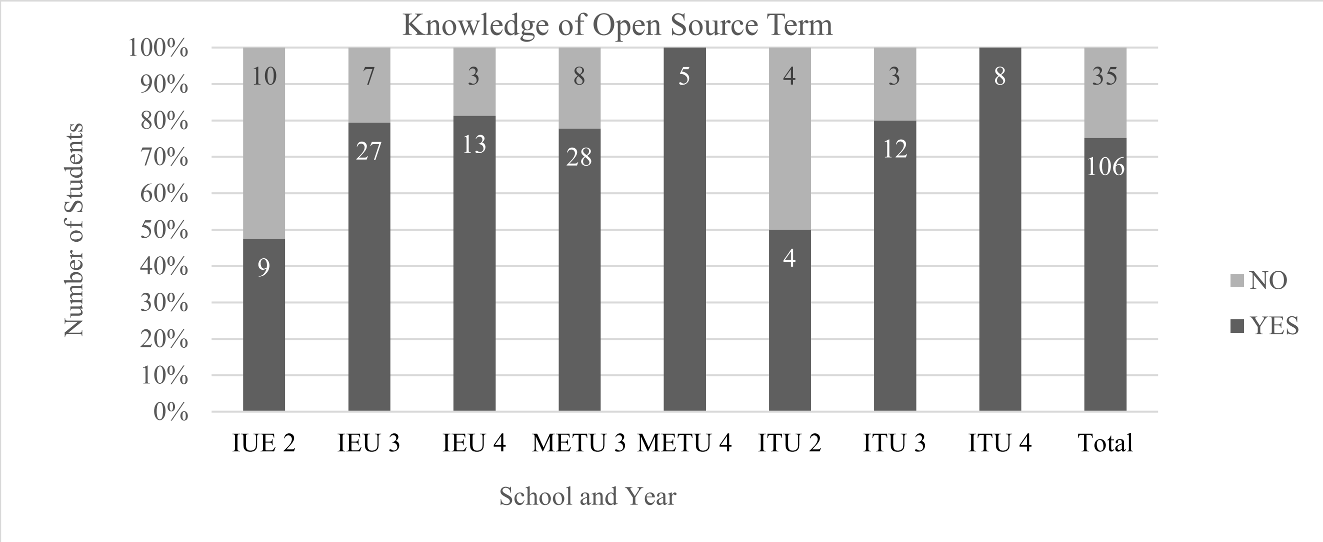


Figure 2. Students' knowledge level of "Open Source" term.

There were two more popular tools for ID students, which were Grabcad and Arduino. Grabcad is easy to use and offers free CAD models which were compatible with many CAD software (Figure 3).

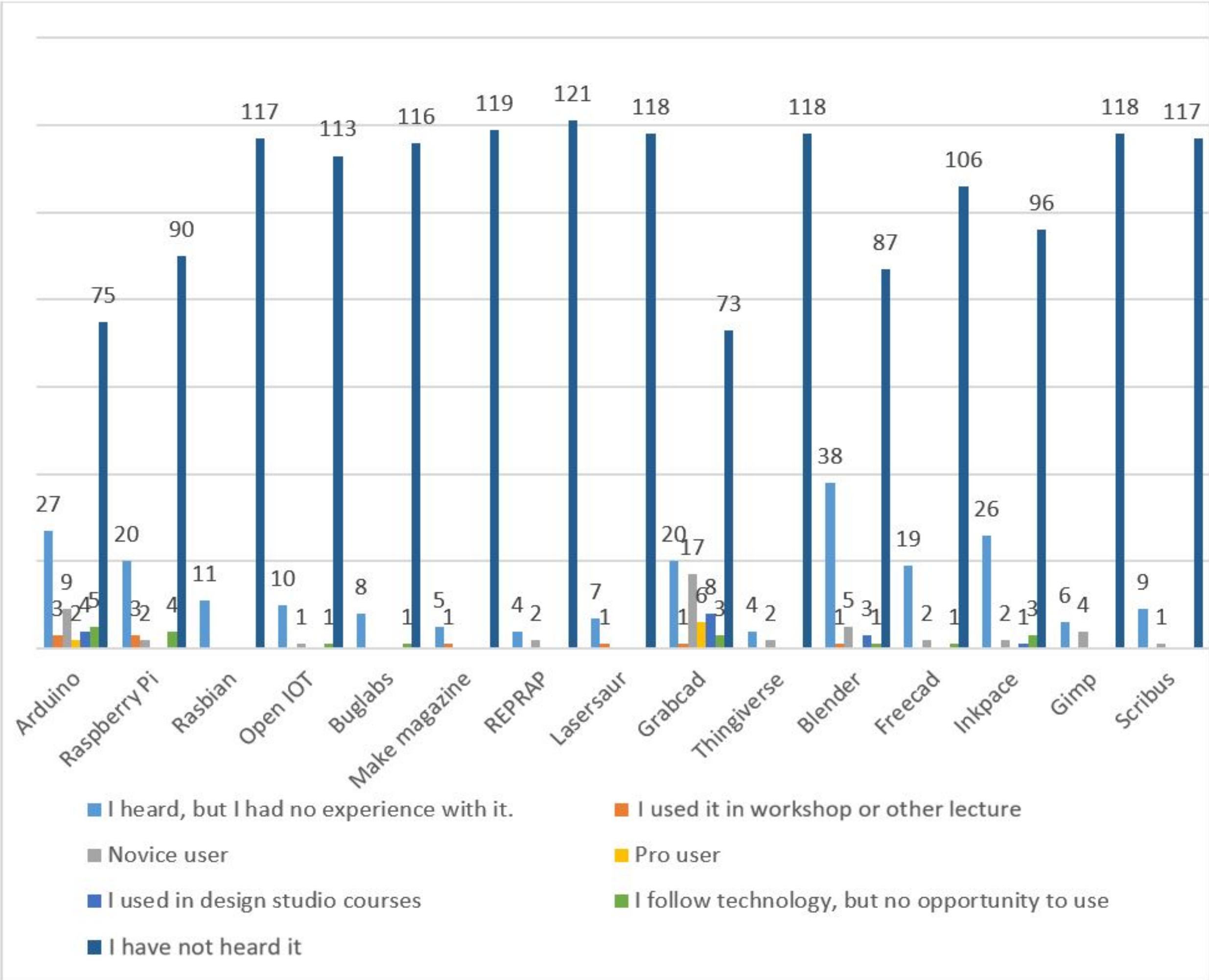


Figure 3. ID students' knowledge and practice level about OST.

One issue with the data was that 75% of students said that they knew the definition of OST, but they also answered "I heard it for the first time" for tools. This answer indicated that students had some experience or knowledge about the tools, or they had heard the definition due to the popularity of software, but they did not know how to integrate it in design projects.

2nd questionnaire for feedback session about OST for ID students

In the feedback session, the 2nd questionnaire was answered by students at ITU, METU and IUE. The 2nd questionnaire had two parts: pre-presentation and during the presentation. In the pre-presentation section, there are two questions which asked about the year of the student and if students know about OS. Questions were answered in parallel with a presentation by students. There are six questions in this section. The 3rd question aimed to learn the students' definition of the OS term and whether or not they clearly understood how OST worked. In the 4th and 5th questions, students' opinions analysing their difficulties in design tasks and their reasons were solicited. The 6th question asked about OST and students' relationship with each tool. The 7th question was asked to find out about any tool that could be helpful if students had learned about it before the project. In the last question, students were asked to provide any other ideas or opinions.

Data Analysis of Feedback Session

After presenting each tool, students answered the question with 7 options (Appendix 1). Students indicated that they had heard of KAA, Thingiverse, and Raspberry Pi for the first time in the presentation. Arduino, Instructables, and Grabcad were the most well-known and commonly used OST by most ID students. All found the advice about Arduino, Grabcad, and Thingiverse useful for their design process. On the other hand, a few were sceptical that Raspberry Pi, KAA, and Arduino would be a good choice for design studio courses. All participants emphasized that any tool could be helpful if they learned it before the project. Despite their limited knowledge, students built a connection with OST as a useful design tool to clear up difficulties in specific tasks.

Simulation of OS Community

After the case study session in three different universities, a workshop session was designed to understand the usability of OST in ID studio projects. According to the feedback session, students had positive opinions about using OST in their design process.

Pilot study 1: redesigning previous design studio projects with OST
In OS, people can modify the source and share because its design publicly accessible so the modification capability is the main characteristic of the source. Re-designing one of their previous studio projects with OST aimed to determine the differences with or without use of OST in the design process. According to the first questionnaire's results, R1 showed some difficulty in T1, T12, T13, T19 and CT20. R2 has some problems with more than five tasks in design studio projects, and the reasons were similar to R1's. R3, R4 and R5 reflect difficulties in digital modelling, budget, time and idea generation. A need to design Pilot study 2 emerged due to the unsatisfactory design process in Pilot study 1.

Pilot study 2: using OST in a design studio project
Students did not redesign their previous project. Thirteen students volunteered at the beginning to participate in this research. They are from six different universities: five students from Isik University, two from Anadolu University, three from Kadir Has University, one from ITU, one from METU and one from Ozyegin University. Three students are from the 2nd year, seven from the 3rd year and three from the 4th year. The result of pilot studies showed that students are not willing to learn new tools during the ID studio course or when redesigning their previous projects. Most of the OST were new for the students. Thus, they needed to practice before using them in design studio courses. Also, offering them only tools with specific ways of use was not an effective and permanent solution to develop the students' habit of open source use. Students should learn how an OS community was working with all the elements: developer, source, sharing activity and contributors. For this purpose, a simulation of OS culture was designed to see what kind of behaviours and activities ID students perform and what the impacts of simulation are for students. The simulation aimed to create an effective environment offering an experience of open source tools with all the elements such as source, sharing, contribution and community. A session was run parallel with

the semester, and students were followed through the entire design process, week by week, for their first project in the fall semester of 2016-2017.

Primary Research: Simulation of OS Community

The simulation was performed in the *Introduction to Design Thinking Course* in the ID Department at ITU in the fall semester of 2016-2017. Reasons explaining the need for the OSC simulation in this course were explained by the lecturer as the following: design thinking includes empathy, prototyping, co-design and co-working in the scope of the course. It is similar to OST regarding these aspects. Design thinking is partially applied as a design research step in the ID studio courses. Students' term project was a cup designed for a persona and considering the brand. Persona is accepted as the common point of design thinking and OS. Persona is a representation of the needs, thoughts and goals of the target user. In an OST, persona would be transformed into the contributor. The contributor is everyone who has contributed something back to the project. The simulation took a total of five weeks; after the 5th week, students began to create their OST.

Week 1: The content of the simulation and Instructables were introduced to students. Instructables is a website specializing in user-created and uploaded do-it-yourself projects, that lets you explore, document, and share your creations. Students were then given a first-week assignment of creating an Instructables profile, uploading their design, persona and brand studies to their page, then examining each other and commenting on one another's projects. The first-week assignment was for students to share their design for the week on Instructables. Nine students shared their design on Instructables. Students were identified with a number and abbreviation of a keyword that was related to their project.

Week 2: Each student presented their work and Instructables experience, and then a short lecture about OST and a contribution session was held. As an assignment, students were to have continued developing their projects according to the outcomes of the contribution session. A SWOT analysis was performed as a structured co-working session. Each student mentioned their concerns and additional ideas for the current product design, and then every student offered ideas about the strengths, weaknesses, opportunities and threats of the product. The reason for using SWOT is to offer a specific tool for students to use when contributing to each other's projects, instead of only demanding that everyone would contribute to each other's projects. In the SWOT analysis session, students used A3 paper and post-its. They divided the paper into four areas, offering ideas for strengths, weaknesses, opportunities and threats. Then, classmates wrote their ideas on post-its and stuck them to the related part of the paper. Thus, students could evaluate ideas more easily and clearly. As a 2nd assignment, the student would continue to develop their ideas, update their Instructables, and contribute to each other's projects. Moreover, they had to consider SWOT analysis while developing their design.

Week 3: Arduino was introduced to students as OS hardware, and they created simple Arduino circuits and learned its basics. For this purpose, Arduino, breadboards, jump wires and

LEDs were supplied for students by Inno FabLab. The given example could be the easiest one to build with Arduino, but the aim was making and exploring on one's own or with friends, not with an expert on the subject. After a few attempts to connect wires and LEDs and run codes, each student succeeded in making their LED blink (Figure 4). Then, students had to work on an interactive version of their cup design with Arduino. Although they did not have the required hardware, such as sensors or modules, some basic modules such as temperature or pressure were supplied for them so that they could present their ideas, findings from OS research, and circuit design using some online tools such as Fritzing or circuits, as well as their concept of interaction. After that, an interactive design process was requested in the rest of the project duration.

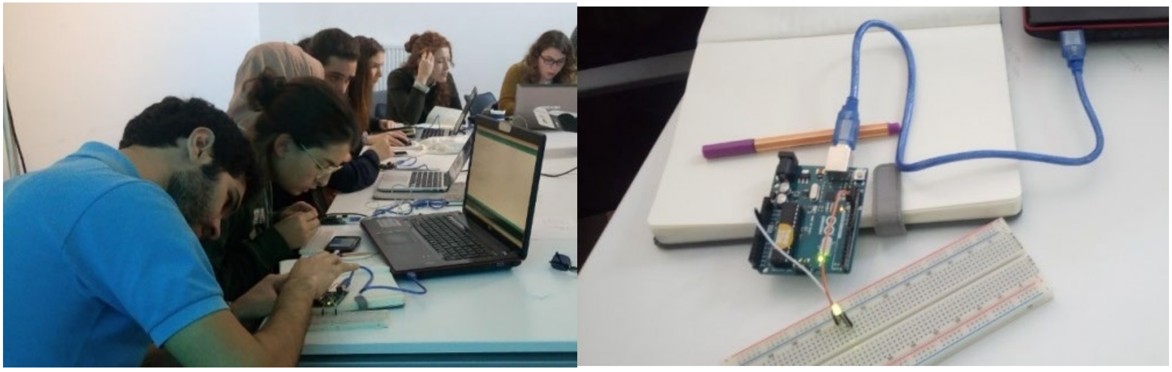


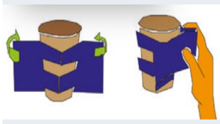
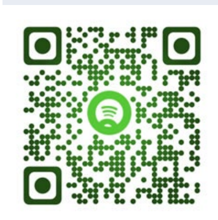
Figure 4: Students built their circuits to blink LED & blinking LED circuit with Arduino

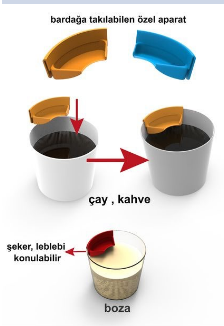
Week 4: Students continued working on their design and using OST in co-working sessions, and they asked about Arduino and sensors based on their needs.

Week 5: According to lecturer and teaching assistant opinion for this session, Arduino was the most tangible expression of OS practice for ID students, because they were used to dealing with products, but considering sharing as a movement and reflecting it in their design process were insufficient to fully understand OS. However, the students could use OS as both hardware and software with Arduino. Moreover, this usage affected their design process, and some of the students wanted to continue with this side of exploration. Furthermore, their lack of knowledge about coding made it necessary for them to use OS.

OSC session through selected students' cases

In this section, the aim was exploring students' projects before and during the open source community session in the course, and then evaluating implications of open source tools usage in their design process. The evaluation of the implications was based on basics of open source such as source, sharing, and contribution. During this section, three cases were-S1Grab, S4Fshp, S8Cmp- selected, because they fulfilled all the requirements asked throughout the whole process. The cases were evaluated to understand adoption level of open source tools in student' design process, and which element of open source is more effective for students.

Code	*Age*	*Gender*	*Initial Design*	*Theme/Aim*	*Final Design*	*Changes*
S1Grab	21	F		Natural and warm feeling		Rather than combining two materials in production level, giving people customized pieces
S2Geo	21	F		Eco-friendly and geometric patterns		Using cups already on the market and adding some details based on theme
S3Cont	20	F		Contrast and practical		Focusing on user need in function level
S4Fshp	21	F		Friendship		SWOT analysis showed that using form to give the sense of togetherness is hard to store and not functional, creating wearable pieces with both function and technology.
S5Cpfy	21	F		Spotify and mood		Using a cup already in coffee houses and adding details with a qr code to create its effect

S6Mlt	20	F		Healthy lifestyle		Focusing on what her persona is already using and designing customizable and printable parts
S7Meas	21	F		Measuring things and controlling habits, LEGO		Giving effect of adding parts to each other with inspiration of LEGO
S8Cmp	21	F		Compact		Rather than changing cup at the production level, a flexible part that can be used with any drink and snack or additive combination, 3D-printable based on needs and cups' dimension
S9Heat	20	F		Safety		Rather than using many layers to create high-level isolation, a do-it-yourself (DIY) holding surface and colour-changing alert for any cup
S10Fld	20	M	He attended class later	-		He did not have any initial design

S11X	21	M	Shared his design in class only, not on Instructables	-	-	-
S12Y	22	M	Did not share any design in class or on Instructables	-	-	-

Table 4. Students' initial and final designs with themes and modifications during the OS session.

S1Grab used the form and some patterns in her first concept before brand analysis, then she decided to change her choice of materials to create a warm feeling. She aimed to capture a sense of belonging through the compact design of cup and spoon. After sharing her concepts on Instructables, she took feedback from her classmates. At this point, she had created a source and shared it. With the feedback of her classmates, OS community was built around the S1Grab's product design. Having taken feedback on Instructables, she added more wood surface to improve the design project and used two materials to make her product larger. The product had a regular form from outside, but it had a convex form inside. The SWOT analysis indicated that she needed to pay attention to manufacturing method, joining details and hygiene. Due to the hygiene problem and challenging manufacturing process of the previous version, she decided to use a detachable cork part instead of wood. However, the feedback indicated that this form was not easy to create. In the OS hardware session, only basics of Arduino and how to find and run the source was taught, so during the rest of the session they did research to work Arduino circuit.

S1Grab designed a DIY product instead of mass production, as the final design, she prepared a guide to show how people can produce her design. S1Grab used felt cloth instead of wood or cork, so the problems of manufacturing and hygiene were eliminated. Her guide which was shared on Instructables was easy to understand. Moreover, the presentation of her design on Instructables showed a designer touch; she considered not only the users and the production process, but also users' experience with this product. In the final step, she offered customization. This shows that her product developed step by step with the consideration of each feedback. She also designed an interactive version of "Relish" in the scope of OS hardware session in the class. She aimed to design a reminder for people who forget their hot beverage which results in it becoming cold. She decided to use Lilypad which is sewable Arduino for wearable technologies, temperature sensor, coin battery holder, LEDs, conductive thread and thin fabric which enabled light transfer. Moreover, she added customizability features into an interactive version of "Relish". During the five weeks, S1Grab reflected sharing activity and interaction with feedback as open source's elements. She integrated each piece of feedback into her concept step by step, such as changing the material of the product.

S4Fshp focused on friendship theme with inspiration from friendship bracelet. She shared her paper cup mock-up and wanted feedback on her Instructables profile and then, she decided to share the story behind her design with persona analysis. She defined her persona and the cup design as:

"The persona likes simplicity and comfort, care about memories and friendships, wants to remember always. Regarding product, the persona prefers light, coherence, endurance, and eco-friendly. The cardboard cup is designed as friendship cups. Every unit should be part of one thing. It is aimed that while they are using the product, it will remind "the part of one (friendship)." For that reason, units are designed like puzzle parts. They make a holistic image. There are some alternatives for both units and the total image. This effect will be made with applying of colours and form."

After sharing the design on Instructables, she took feedback such as trying different forms to create modularity, storage together, trying a different material combination to embrace product family. S4Fshp decided to use different materials. During the SWOT analysis, she took similar feedback. As a result of the SWOT analysis, she focused on form to make manufacturing easier. Her new design had cup sleeves instead of cup itself. These sleeves were set with three combinations, so when a group of friends want to buy a cup of coffee or another drink with these sleeves, then they can keep them and use as a bracelet. After that, she looked for basics of Arduino, while she did her research, she focused on wearable technologies mostly. After the OS hardware session with Arduino, she designed interactive and communicative friendship sleeve bracelet. The interactive version aimed that when one of the friends used a bracelet or sleeve again, then it sends a message to other's mobile phone or other's sleeve which blinks LED. She also used Lilypad, because it is flexible and easy to sew. In the final presentation, she showed her interactive sleeve design and explained the instructions: Cut the patterned fabric and interlining according to template with the seam allowance. (a), Iron the fabric and interlining for joining. (c), Apply these steps for another face. (d), Lay out velcro parts to two edges. (e), Sew velcro on fabric. (f)

At the end, S4Fshp's design's last phase showed the advantages of co-working and taking feedback. At the stage of OS hardware, she made extensive research to compensate lack of experience in this area. She used source effectively as open source's components.

S8Cmp focused on a personalized cup design, she aimed to offer a new experience with drinks and a side compartment that could be integrated into the cup. The feature of the personalized cup was inspired by her persona and favourite object analysis as mentioned before.

Her first mock-up offered a compartment to serve tea in. According to the feedback on Instructables, she needed to work on the leaking problem, she needed a spoon or a detail which could work as a spoon, a compartment for bulk tea instead of a tea bag, and a cup or thermos as a function. After the feedback, S8Cmp divided her cup into two parts to keep utensils for the drink experience, but there were still leaking problem and complex manufacturing process. In the SWOT analysis, feedback showed that connecting between traditional experience and OS may provide more engagement. She decided to design a colourful and interactive coaster to offer customizable service for each customer. In this phase, she had the most detailed work with Arduino with the help of another user which reflected contribution as open source' elements. Their work showed the result of interdisciplinary co-working. In the end, her product used a 3D printer, so she did not have to deal with leaking problem. Through the use of OST components -source and contributions- her project was levelled up.

Other Implications with OST

In addition to selected cases, other students' design process had some stages that needed analysis. These stages show alternatives views about OST use in their design process. In the 3rd week, S5Cpfy shared her new findings and developed parts on her design. She wants to design an espresso cup which offers interaction with the customer through a Spotify music list. She found dynamic QR code to add to the design different from the ones in previous weeks.

With that, S1Grab and S6Mlt claimed that they learned dynamic QR code and offering interaction with it thanks to her Cupify project, so it may give inspiration to other people, too. This indicates that students accept sharing activity of OS for only complex production or very interesting ideas, but the point is sharing and taking feedback, then move the project one step further.

Another remarkable thought was expressed by S12No. He did not present any projects idea. According to his opinion, many posts on Instructables did not have a design or product value. He also expressed his opposition against sharing his own ideas with a group of professionals without obtaining an economic benefit. He believed that one should start a Kickstarter instead of posting on Instructables if the design idea was good enough.
S2Geo started with a recyclable material cup with geometric pattern, and she wanted to add some seeds on it for the secondary use of the cup. However, she did not find the direct way of doing it, instead, she designed the gift idea with seeds. Then, she designed a water level controller for plants. All steps of her design were not connected with each other through a cup design, but she still continued with the eco-friendly concept, and used sharing and sources as OS elements.

S9Heat designed a safer cup with stronger isolation at first then she decided to include a thermocolour (colour-change) feature to the design. In the interactive design, she also designed a coaster which integrated a tiny piezo buzzer and temperature sensor. When the temperature of the hot drink reaches to 65°C, the speaker functions.
In addition to the design process and OS session in the class, students used OST in their previous design. For example, S6Mlt had designed a cocktail glass in her previous design studio courses, and she decided to add interaction to her glasses for parties and cocktails. The aim of interaction was building communication with the waitress, when a customers' drink is finished. For this purpose, she decided to use a load cell in the cocktail desks which sense the weight of the drink; then it sends signals to waitress. Moreover, she shared on Instructables and wanted help from other Arduino users. Using OS outside the class and without any obligation shows that she may adopt it as a design element and usable in the design process.

Similar to S6Mlt, S4Fshp also shared her previous design on Instructables. She published instructions of her previous "Bookside" project. She did not need any support with her design. Furthermore, she said that she just wanted to share and see other people produce her design. This indicates that students adopt OS to interact with communities and become part of the communities.

Adoption of OST use into students' design process

According to questionnaire data (Appendix- I*)* students found the experience regarding, OST and communities useful. Eight students agreed on the session's positive contribution to their design

process, but three students claimed that this made their design process slower. Two students did not find OST effective or useful for their design process. The question of students' anxiety about sharing their design was asked, with responses rated on a 0-to-10 Likert scale, where 0 indicated students had no anxiety to share, 5 indicated students had some anxiety, but it did not prohibit sharing, and 10 indicated that students had anxiety and did not want to share. Only two of students felt anxiety about sharing and were somewhat limited in their willingness to share. Three students chose scale 5 to represent their anxiety, and the remaining students had less anxiety about sharing.

According to students' feedback about the effects of sharing their design on Instructables, almost every student agreed that comments had a positive effect on their design process. Some comments had helped students when they were stuck; some comments were stimulating for students and made their design process much easier. One of the students said that he found the critiques objective and helpful in his design. Another student's opinion was that comments had helped the transformation of her design from a raw to a more developed product. Students agreed on the positive effects of contributing to each other's projects. Only one student found the contribution to another project time-consuming. Two students said that contribution provided personal satisfaction in helping others' designs. The remaining students claimed that this activity supported their project and their personal development.

Moreover, two students gave an answer indicating that contributing to other projects had contributed to both their projects and themselves.

In the weekly classes and assignments, students had to do research and find OST to build their Arduino prototype. There was a question asking about how hard or easy the process of finding knowledge from an OS was. It was asked to evaluate their research process with OS. Only one student found it hard, five of them saw it as a normal process, and four of them agreed with its easiness. Students had some difficulties due to their lack of practice so far, but the majority thought positively about learning Arduino and gaining this experience for their further projects. Due to the course structure, all students used Instructables. Although a part of the course included Arduino, not all students used Arduino. To find a 3-D model for their design, students used GrabCad and Thingiverse. One student chose the option for another tool, but he did not specify which one. Students' opinion was that learning these tools would be helpful for further projects if they needed to design an interactive project. Students understood that Arduino, coding or electronics were not that difficult if they needed clear and OS to learn from.

Discussion and conclusion

Pilot study 1 showed that students need more time and practice to engage with OST. In the 2nd pilot study, students' feedback indicated that they needed more time, more practice and knowledge before using OST in studio course projects. Moreover, students had no motivation to work with OST and did not want to use anything without the lecturers' notice. Students had become used to designing for economic value, so sharing their design free of charge was not a usual situation for them. Thus, students needed to understand why people shared their design and other works for free. For this purpose, students could meet with those people and interview them to improve their understanding. The primary research included an OS session in the ongoing course, so students had some confusion about how they were to continue on their projects. Even in the 4th week, students were clear whether they had to include their previous work, such as persona or brand, or needed to design a do-it-yourself (DIY) product. Students' feedback in the evaluation session showed that they could not engage with the reasons for sharing their projects. Although students had limited knowledge they were able to overcome the obstacles generated by specific tasks via using OST as a useful design tool. This feedback supported the reasons of technical knowledge and technical support that were analysed as the result of the first questionnaire. However, according to their answers, students also took a positive approach to using OST in their design studio course projects. Follow-up studies were designed to find an effective way to encourage ID students to use OST in their projects. The last step of the research, OSC session showed that an effective way of creating engagement between students and tools was offering all elements of OS, such as hardware, software, community, and platforms. Without using it in their design, most students did not see OST as a design element. That there was a gap in the students' perception and experience of design culture today - between professional ID and increasing practices of OD - but they began to see the connections. Furthermore, with the co-working and contribution elements of OSC, students overcame the difficulties including decision skills, expressing concepts correctly and quickly, finding inspiration, generating sufficient ideas, changing and developing ideas. A great majority of students agreed with the positive effects of contribution to each other's projects. Students believed that learning these tools would be helpful for further projects if they needed to design an interactive project.

In contrast to the offerings of OST for ID students, some students also expressed views about their occupation. They interpreted the definition of industrial designers as designing a product with economic value so the product could find a place in the market, thereby earning its company money. In this circumstance, students did not clearly understand why they shared their design with others. In consideration of this definition, they should not use OST, because these tools could not be used as commercially. However, as the opposite of this definition, some of the students mentioned personal satisfaction due to contributing to another project. This process was the driving force for OS users and people sharing projects. Students' knowledge about OS transformed from a basic definition to all elements and experience.

OST and community positively affected students' experience of their design process and made it more rapid. As seen in the examples from many disciplines, OS could be used in education to set new skills to students for preparing them to solve today's and future's problems. They could support their lifelong learning with OS, so teaching and adopting OST into ID education could contribute students' development not only prepare them as competent for the industry but also competent to solve any complex problems of future in a multidisciplinary environment. OST can be taught in class, and students can pick a project to develop themselves instead of being given a specific theme and obligation. Moreover, contacting any project owner from any OS platform and contributing to it can be required of students so that they can be part of a real community. The way to create engagement between ID students and OST is to build an environment with all OS elements. Within this environment, students experience the whole process, starting from source, sharing, and contribution to the community. Then, students begin to accept these elements as design tools. Moreover, they contribute to OS by doing things such as sharing their designs, developing them with the community and giving feedback to others, so they contribute their design perspective into OS as much as they learn from it.

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Statements on open data, ethics and conflict of interest

Data used in this study can be accessed via the following link: https://cloud.iyte.edu.tr/index.php/s/HzLi7lP8Md1d8T1

The study was conducted and approved under the ethical guidelines in place at the Izmir Institute of Technology for all graduate students. The participants volunteered to complete the survey in the present research. The students in the simulation phase were enrolled in the course *Introduction to Design Thinking Course* at ITU and graded in the fall semester of 2016-

2017. Besides, all figures, explanations and posted comments about ten students' projects were available on Instructables:

S1Grab http://www.instructables.com/id/Fundamentals-of-Design-Thinking-the-Development-of

http://www.instructables.com/id/Design-Thinking-the-Coffee-Cup-Part-I/

S2Geo http://www.instructables.com/id/Cardboard-Cup/
S3Cont http://www.instructables.com/id/Contrast-Cup/
S4Fshp http://www.instructables.com/id/Design-a-Cardboard-Cup-With-Design-Thinking-Method
S5Cpfy http://www.instructables.com/id/Cupify
S6Mlt http://www.instructables.com/id/ArduinoCupDesign/
http://www.instructables.com/id/Fundamentals-of-Design-ThinkingCup-Design/
S7Meas http://www.instructables.com/id/Design-Thinking-Cup/
S8Cmp http://www.instructables.com/preview/E5WL9U6IUKF06CN/
http://www.instructables.com/id/Fundamentals-of-Design-Thinking/
S9Heat http://www.instructables.com/id/Design-Thinking-Cup-Design/
S10Fld http://www.instructables.com/id/Collapsible-Cup

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APPENDIX 1

EVALUATION OF INDUSTRIAL DESIGN STUDENTS' DESIGN PROCESS TASK BY TASK AND THEIR AWARENESS ABOUT OPEN SOURCE

This questionnaire was applied for Zeynep Aykul's MSc Thesis in Industrial Design Department at IZTECH. In the first chapter, there are two parts which are difficulty rates design tasks and reasons design tasks. In the second chapter, knowledge of students about open source term and open source tools are asked.

1. Name and Surname

2.E-mail

3. School/Year

Tasks and Their Difficulty Rates

4.Please, mark your difficulty rate for each task in the design studio projects. *

	It is not difficult	A little difficult	Somehow difficult	Difficult	Very Difficult
Data collection and Analysis	◯	◯	◯	◯	◯
Data presentation	◯	◯	◯	◯	◯
Understanding project theme	◯	◯	◯	◯	◯
Understanding project needs	◯	◯	◯	◯	◯
Producing enough amount of ideas	◯	◯	◯	◯	◯
Developing and changing ideas	◯	◯	◯	◯	◯
Express the concept quickly and correctly	◯	◯	◯	◯	◯
Finding inspiration	◯	◯	◯	◯	◯
Generating form and style according to user's need	◯	◯	◯	◯	◯
Finding reference knowledge	◯	◯	◯	◯	◯
Decission ability	◯	◯	◯	◯	◯
Evaluation criteria	◯	◯	◯	◯	◯
Meeting expectation of lecturer	◯	◯	◯	◯	◯
Digital modelling	◯	◯	◯	◯	◯
Physical modelling	◯	◯	◯	◯	◯
Preparing presentation poster	◯	◯	◯	◯	◯
Preparing presentation organization	◯	◯	◯	◯	◯
Affording budget for presentation	◯	◯	◯	◯	◯
Delivering project on due date	◯	◯	◯	◯	◯
Affording budget for overall project	◯	◯	◯	◯	◯

Reasons of difficulty for design tasks

In this section, you will answer reasons of difficulties of tasks as the same as the previous question.

5. Please, mark your difficulty reason for each task in the design studio projects.

	Experience	Technical Knowledge	Budget	Time	Technical Support	Relevant Courses	Lecturer	Classmates
Data collection and Analysis								
Data presentation								
Understanding project theme								
Understanding project needs								
Producing enough amount of ideas								
Developing and changing ideas								
Express the concept quickly and correctly								
Finding inspiration								
Generating form and style according to user's need								
Finding reference knowledge								
Decission ability								
Evaluation criteria								
Meeting expectation of lecturer								
Digital modelling								
Physical modelling								
Preparing presentation poster								
Preparing presentation organization								
Affording budget for presentation								
Delivering project on due date								
Affording budget for overall project								

Measurement of Awareness about Open Source Term and Tools

In this section, your knowledge about open source will be measured.

6. Did you hear term of "open source" or "açık kaynak"?

- yes
- no

7. Mark your relationship about each open source tools

	I heard it, but did not use before	I participated its use in workshop etc.	novice user	pro user	I used it in design studio course project	I am following the tool, but no opportunity to use	I did not hear it
Arduino							
Raspberry Pi							
Rasbian							
Open IoT							
Buglabs							
Makezine							
Reprap							
Lasersaur							
Grabcad							
Thingiverse							
Blender							
Freecad							
Inkspace							
Gimp							
Scribus							

Additional

If you used any tools in your class, then please answer the question.

8. Did you use open source tools which you marked in previous question or another one in design courses? Please note your aim and experience. *

APPENDIX 2

FEEDBACK SESSION OF INTRODUCTORY PRESENTATION

Pre presentation Section

This survey aims to take feedback about my presentation. For further information on your questions, you can send me email to zeynep.aykul@gmail.com

1.Your School/Year (If you want to take information e-mail about open source and further studies, you can write your email)

____

2. Do you know term of "open source"?

- Yes
- No

During Presentation Section

You should answer these questions during the presentation.

3. Did you understand Open source terms and system?

- yes
- no
- not clear enough
- Diğer: ________________________________

4. Do you think that I analyzed challenging tasks of industrial product design students and reasons of them in studio courses?

absolutely true	true	there are some missing points	there are wrong analysis

5. If you think there is mistake or missing point in previous question, you can add here.

6. In this question, can you pick the best option for you in each project sample?

	I heard it for the first time	It was interesting tool	Advises are useful, I may use it in future project	Advises are not enough	Advises are useful, but they are not effective for studio project	I am already a user
No:1 GRABCAD						
NO: 2 INSTRUCTABLES						
NO 3: THINGIVERSE						
NO 4: ARDUINO						
NO 5: RASPBERRY PI						
NO 6: KAA-PLATFORM						

7. Did you think about any tool which could be helpful, if you learnt before the project?

8. If you have any additional opinion or idea, you can add this part. Thank you.

APPENDIX 3

Evaluation form for Simulation of Open Source Community

The aim of this form is evaluating 5 weeks process in the "Introduction to Design Thinking" course. the study is run by Zeynep Aykul as master thesis study.

1. **Name-class**

   ____

2. **What is mean of open source for you?**

   ____

3. **What is open source community? Please answer based on your experience in the class.**

   ____

   ____

   ____

4. **Do you think open source tool contribute your design process?**

   Uygun olanların tümünü işaretleyin.

   - [ ] No contribution
   - [ ] Limited contribution
   - [ ] positive contribution, fast process
   - [ ] positive contribution, but slower process
   - [ ] negative effect, it was hard to focus on my project
   - [ ] negative effect
   - [ ] Diğer: ______________________________

5. **Did you anxious about sharing your design? 5= I feel few anxiety, but it was not obstacle to share.**

   Yalnızca bir şıkkı işaretleyin.

	0	1	2	3	4	5	6	7	8	9	10	
no anxiety	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	very anxious, I did not want to share my design

6. How did comments on Instructables affect your design process?

____

____

7. What did you think about contributing others' projects?

____

____

8. Affects of contributing others' projects:

Uygun olanların tümünü işaretleyin.

- [ ] It was time consuming
- [ ] It made me hardly focus my own project.
- [ ] It also contributed my design process
- [ ] It provided personal satisfaction.
- [ ] It provide me to develop myself in different topics.
- [ ] Diğer: ______________________________

9. Reaching knowledge for open source tools was....... for me.

Yalnızca bir şıkkı işaretleyin.

	1	2	3	4	5	
very hard	○	○	○	○	○	very easy

10. How do you evaluate your experience with Arduino?

____

11. **Which open source tools did you use in your project?**
Uygun olanların tümünü işaretleyin.

- [ ] Arduino
- [ ] Instructables
- [ ] Grabcad
- [ ] Thingiverse
- [ ] Diğer: ______________________

12. **Will you use your learning from this class in your future projects?**

____

____

____

____

13. **other...**

____

____

____

The roles of material prototyping in collaborative design process at an elementary school

Varpu Yrjönsuuri, Kaiju Kangas, Kai Hakkarainen and Pirita Seitamaa-Hakkarainen, University of Helsinki, Finland

Abstract

Co-invention projects in elementary school engage pupils in complex, open-ended design tasks in a practical, hands-on way. Physical materials are an intrinsic part of design, involving trasformation of conceptual ideas into material forms, such as prototypes. These tangible objects mediate embodied thinking and act as material-social mediators of knowledge creation processes. However, the material properties of the designed artifact and pupils' varying skills and levels of material knowledge constrain the design process.

While previous studies of materiality in design have mainly focused on adults, this study aims to analyze and describe the different roles of material prototyping in an elementary school collaborative design process. A co-invention process was conducted in a Finnish elementary school during spring 2017, with the task of designing solutions for everyday problems. The data consisted of six video recorded design sessions, where small teams of 5th graders prototyped their inventions. We analyzed the video data across macro-, intermediate-, and micro-levels.

The results revealed that pupils used prototypes as mediators for ideation and collaboration. They tested their ideas with prototyping, and material manipulation occurred during collaborative ideation. Material representations supported the verbalization and demonstration of ideas. Some challenges also emerged; prototype construction was a slow and laborious process, the division of labor tended to be unevenly distributed, and the model took a dominant role over the designed artifact. We conclude that support from the teacher and the learning environment is critical for utilizing the full potential of material manipulation in an elementary school setting.

Keywords

prototyping, collaborative designing, elementary school, maker-centered learning, materiality, video analysis

Introduction

Maker-centered learning offers pupils the opportunity to engage with the world by designing, making, and knowledge creating (Clapp, Ross, Ryan & Tishman, 2016; Peppler, Halverson & Kafai, 2016; Seitamaa-Hakkarainen & Hakkarainen, 2014). In recent years, much research has been conducted to investigate pedagogies and practices of maker-centered learning, where making broadly refers to various activities of creating, designing, building, and tinkering (Ryan, Clapp, Ross & Tishman, 2016). Currently, many educators have been interested in the global maker movement as it has provided various informal and out-of-school hands-on learning opportunities for pupils to enhance and cultivate skills in the fields of science, technology, engineering, arts and mathematics (STEAM) through creative use of digital fabrication technologies (Honey & Kanter, 2013; Blikstein, 2013). While maker-centered learning emphasizes self-directed learning, engagement, risk taking and using failures as creative learning opportunities, it also highlights the importance of iterative processes of designing and making in collaborative settings (Ryan et al., 2016). Although in the out-of-school programs, students usually work on individual projects, solidarity with others and the opportunity to contribute to their work are highlighted (Petrich, Wilkinson & Bevan, 2013, 157). In a school context, collaborative work is more common: the design project emphasizes sharing and pursuing a shared purpose with other team members, and the team builds on and adapts to ideas, while helping each other to achieve goals (Kangas, Seitamaa-Hakkarainen & Hakkarainen, 2013a). Learning to use various traditional and digital tools for creative purposes and understanding the potentiality of materials are all important components of maker-centered learning pedagogies (Ryan et al., 2016; Seitamaa-Hakkarainen & Hakkarainen, 2017).

Challenging and authentic design tasks provide meaningful contexts for young pupils to participate in practices of knowledge-creating learning in an experimental, hands-on, and collaborative way. "Designerly" ways of thinking and augmentation of reasoning process by the manipulation of materials are the most important qualities of design learning and making; these require creative generation of ideas, as well as critical thinking, particularly when conceptual ideas and material aspects of the process reciprocally support one another (Kangas, Seitamaa-Hakkarainen & Hakkarainen, 2013a). The emerging design artifacts and prototypes provide implicit hints and guidelines regarding how to further elaborate ideas (Knorr-Cetina, 2001); hence, the creative process has a material basis. According to Deininger, Daly, Sienko, and Lee (2017), prototyping and material model making can be seen as a combination of different techniques that allows physical or visual form to be given to a design idea (Alesina & Lupton, 2010; Kelley & Littman, 2006), which can be evaluated from various perspectives. The invention process is inherently object-driven in nature, involving a nonlinear creative pursuit of envisioned "epistemic objects", instantiated in a series of successively more refined artifacts and productions (Knorr-Cetina, 1999, 2001; Rheinberger, 1997; Paavola & Hakkarainen, 2014; see also Wagner, 2012). Such epistemic objects are defined by their openness, their "lack of completeness of being" and "capacity to unfold indefinitely" through successive imperfect but affect-laden instantiations (Knorr-Cetina, 2001). Thus, the iterative interaction between thinking and making is pivotal (Kimbell & Stables, 2007) and physical materials are an intrinsic part of the process: conceptual design ideas are transformed into various material forms, such as sketches, mock-ups, prototypes and final artifacts.

Material embodiment appears to be a constitutive characteristic of maker-centered learning that provides ample opportunities to observe, imitate, and appropriate instrument- and materially mediated creative activities. Learning by making is entangled not only with human but also non-human agents, such as the material tools, resources, and spaces. Presumably, the making process relies on an "embodied mind" where mental imagery together with material exploration support the dynamic generation of successively more refined artifacts embodying progressing design ideas. In design and maker-centered learning children learn technological skills by engaging with materials and building structures or devices (Rowell, 2004). Prototyping with materials includes analyzing design constraints and seeking feedback through experimentation with materials and structures. Materiality concretizes the iteration in the design process: materialization of design ideas makes them visible for joint evaluation and development (Binder, Michelis, Ehn, Jacucci, Linde & Wagner, 2011), and material representations can be tested and further refined (e.g. Welch, 1998). Designing and making have enormous potential to provide direct experience of new materials, tools and technologies. Moreover, design and making activities should develop young pupils' personal and social abilities to enhance and transform ideas, provide opportunities for inventive solutions, and confidently express ideas about sketching and model making (Welch 1998; Welch, Barlex & Lim, 2000). Several researchers have noted that small children are not motivated to use drawings (Fleer, 2000; Welch, Barlex & Lim, 2000), but instead prefer first to explore with materials and then to construct an artifact. In maker-centered settings, pupils should be encouraged to use different kinds of visualization methods (including 3D CAD visualizations) to externalize their design ideas, build various mock up models, or construct 3D prototypes.

Although the importance of materiality and ability to materialize design ideas has been highlighted, most of the previous research on materiality in design has focused on professional designers or university-level design students (e.g. Gore, 2004; Poulsen & Thøgersen, 2011; Vrencoska, 2013; Lahti, Kangas, Koponen & Seitamaa-Hakkarainen, 2016). Materiality and materialization have rarely been the main focus of studies on young pupils' design and making processes, although a few studies emphasize the importance of materiality (e.g. Kangas et al., 2013a; 2013b; Rowell, 2002; Welch, 1998; Welch, Barlex & Lim, 2000). Therefore, the particular objective of the present study was to analyze the role of prototyping (i.e., mock up models) and material model making in elementary school pupils' collaborative design process. Accordingly, we address the following three research questions:

- How are prototypes used for refining design ideas or the prototype itself?
- How are prototypes used as social mediators of a collaborative design process?
- How do the material properties of prototypes become visible in collaborative design processes?

In the following, we will take three perspectives on material prototyping: (1) prototypes as aids for thinking, (2) prototypes as social mediators, and (3) prototypes as material constraints to the process. In the present study, we use prototyping and prototype to cover different material representations produced during the co-invention process such as mock up-models and various material models.

Three perspectives on material prototyping

Kangas and Seitamaa-Hakkarainen (2018) describe collaborative designing as an iterative and cyclical process in which the participants share their expertise in creating a meaningful and authentic design context for analyzing design constraints and proposing ideas as well as for providing feedback in order to develop a shared design object. According to Abrahamson and Lindgren (2014), material objects mediate embodied learning. Building shared prototypes and artifacts makes learning and collaboration tangible. Additionally, Rowell (2002) emphasizes that physical materials stimulate collaboration. These interpretations support the fact that prototypes aid ideation and thinking in collaborative settings.

(1) Prototypes as aids for thinking

Manipulation of materials is a means of embodied thinking, and prototyping can be a way to externalize ideas that might otherwise be difficult to imagine, explicate and verbalize. A prototype could be utilized for testing functional and structural aspects of design (Binder et al., 2011), or visualizing the design ideas being developed (Ramduny-Ellis, Dix, Evans, Hare & Gill, 2010). Illum and Johansson (2012) have pointed out that material representation supports the verbalization of abstract ideas (see also Kangas et al., 2013a; 2013b; Welch, 1998). According to Poulsen and Thørgesen (2011), embodied thinking, i.e., thinking enhanced by working with material artifacts, is an intrinsic part of designing. Kimbell and Stables (2007) emphasize, that complementing cognitive process of imagining by concrete modelling is essential for design capability. In addition, materials offer valuable feedback through iterative model making (e.g. Gore, 2004; Jacucci & Wagner, 2007). Kangas et al. (2013a; 2013b) have studied artifact design in elementary-level education and discovered that embodied activities could help young pupils move into knowledge-creation processes otherwise beyond their capabilities. In professional designing, the various visual representations, mock up models and more detailed prototypes are created frequently and inexpensively at various phases of the process so as to assist designers in identifying design issues, discovering opportunities, and quickly eliminating less promising solutions (Alesina & Lupton, 2010; Deininger et al., 2017). Choosing a specific goal for prototyping is crucial also in the elementary school context (Klapwijk & Rodewijk, 2018). Usually, novice designers consider prototypes as models created towards the end of a process, and not as dynamic tools for developing several simultaneous ideas (Deininger et al., 2017).

(2) Prototypes as social mediators

The social dimension of design learning is crucial. Collaborative designing includes productive thinking within interaction: it is both reflected in and stimulated by discourse between collaborators as they share, evaluate, and revise ideas to support the progress of their design process (Hennessy & Murphy, 1999; Kangas et al., 2013a; 2013b). Prototypes provide material anchors for design activity and interaction that focus on shared design efforts. Through materialization and model making, design ideas become visible for joint evaluation and development (Ramduny-Ellis et al., 2010) and help create a common ground for teams to understand (Lahti et al., 2016). Materials and model building could also affect the division of labor (Lahti et al., 2016). For example, Rowell (2002) has pointed out that possession of a particular tool could also give authority to the use of materials shaped by that tool. Working on the prototypes can help explicate and verbalize vague ideas, but also gestures such as pointing are used in collaborative designing. Gestures occurring when manipulating an artifact can be used to illustrate its functions and usage. Gestures also have a dynamic role in creating and shaping design ideas and stimulate further collaborative refinement of design ideas (Härkki et. al., 2018).

(3) Prototypes as material constraints and inspiration

Besides the material properties of the designed artifact, the design process is affected by the materials used for prototyping. For example, prototyping materials can condition later design decisions (Lahti et al., 2016; Tan, Keune, & Peppler. 2016) and inspire imagination and creativity at the beginning of the process (Alesina & Lupton, 2010; Heimdal & Rosenqvist, 2012). Material design constraints (Lawson, 1997) might, as Ramduny-Ellis et al. (2010) argue, prevent obvious solutions and encourage novel ideas. Furthermore, Ramduny-Ellis et al. (2010) emphasize that the possibilities relating to a certain material in a design task, such as prototyping, are dependent on the designers' past knowledge and skills. A lack of craft skills and, consequently, difficulties in materializing the idea can, according to Groth (2016), result in frustration towards the whole process. In elementary school, material prototyping requires craft skills and material knowledge. On the other hand, prototyping can itself offer pupils personal, embodied experiences of materials, which in turn allow them to build deep material knowledge (Härkki, Seitamaa-Hakkarainen, & Hakkarainen, 2016; Illum & Johansson, 2012). Material prototyping is a relatively slow process (Welch et al., 2000). However, Vrencoska (2013) argues that the slowness of material working can allow time for profound idea refinement. Clapp et al. (2016) state that the tangibility of material working can be engaging and stimulating, owing to, for example, the multisensorial qualities of physical materials (Jacucci and Wagner, 2007). While rich material resources can inspire imagination (Alesina & Lupton, 2010), a limited selection of materials can help pupils to focus on the task at hand (Clapp et al., 2016). On the whole, in addition to influencing the outcome of a design activity, material properties constrain and inspire the work of a designer (Lahti et al., 2016; Lawson, 1997; Ramduny-Ellis et al., 2010).

Method

Participants and the Context of the Study

The data for the present study were collected in a co-invention project that was organized in an elementary school in Helsinki, Finland. This was part of a larger research project in which pupils from several schools were engaged in investigative practices of learning that involved collaborative designing, inventing and constructing artifacts. In all schools, the projects were designed by teachers and researchers together, but the teachers were responsible for implementing the project. In the present study, the co-invention challenge assigned to the pupil teams was open-ended: to find a novel solution for an everyday problem. Three 5th grade classes (75 pupils aged 10 to 11 years) and four teachers participated (one craft teacher and three class teachers). The project involved eleven weekly co-design sessions of approximately 90 minutes each. Teachers worked as pairs: two class teachers (A and B) together and the craft teacher (C) with the class teacher (D). Pupils worked in small teams (3 to 5 pupils), developing their co-invention with the help of teachers, researchers and experts from outside the school.

During the ideation stage, pupils consulted parents, visited museums and met a professional inventor. Pupil teams built one or two physical 3D models of their invention with low-fidelity (low-fi) materials, such as plastic board, play dough and bubble wrap. The purpose of prototyping was to make a non-working model in order to facilitate the teams' work through materialization, and support them in presenting their invention. The classes worked on the design project mostly during their weekly craft lessons. They used the schools' technology education classroom, where the materials and equipment were stored, and their own classrooms and computer labs. The project started with ideation in fall 2016. The teams were formed with teacher support according to pupils' interests. During spring 2017, teams refined their ideas, built the prototype, visited a design museum, and participated in an app-developing workshop. Pupil teams presented their inventions to their classmates and teachers at the school. Some of the teams also participated in an "invention fair" organized at the University of Helsinki. Table 1 presents the spring 2017 project timeline.

Table 1. The timeline of the invention project

2017: January	February	March	April	May
Ideation				
	Prototyping			
		Presentation preparation		
			Museum visit	
			Presentation at school	
				App workshop
				Invention fair

The pupil teams produced various inventions, for example, to facilitate cleaning, division of housework, organization of belongings, and studying. Most of the inventions included essential digital elements, which were modeled with the low-fi materials. Of the 20 teams, we selected three to be closely followed by video recording. We limited the number of observed teams to three for practical reasons, since our aim was to conduct a fine-grained analysis. We selected varying teams. These teams differed in size, gender, and the nature of invention, and were named after their inventions: Kamlele, the Technical Cleaner, and the Multipurpose Chair. The teams' prototypes are illustrated in Figure 1.

Figure 1. From left to right, Kamlele, the Technical Cleaner, and the Multipurpose Chair

Kamlele reminds the user of household chores. The device can be placed, for example, on a dishwasher or on a dog's collar. The personalized ringing tone announces whose turn it is to complete the chore. The device comes in multiple sizes and the color adapts to home decor. The team consisted of five girls. Their teachers were the two class teachers (A and B).

The *Technical Cleaner* facilitates cleaning. For example, it takes pictures of the home, evaluates how messy and dusty it is, and reminds the user to clean up. Group consisted of five members: three boys and two girls. Their teachers were the two class teachers (A and B).

The *Multipurpose Chair* makes studying at school easier. The chair has a sound-isolating hood, which can be lowered when needed. The group consisted of three boys. Their teachers were the craft teacher (C) and one of the class teachers (D).

Data collection and analysis

The design sessions of the selected teams were recorded with two GoPro-cameras: one hanging from the ceiling, and other placed on a tripod, in order to document pupils' gestures and material manipulation during their design activities. In addition, photos of sketches and prototypes were taken after each session. In this study, we focused on sessions where the main design activity was prototyping. Pupils made some finishing touches to the prototypes after the selected sessions, but the basic idea did not evolve significantly. For the analysis, we chose two sessions from each team: a total of six sessions of 90 minutes each. During these six recordings, a wide variety of prototyping actions appeared.

In order to create systematic and focused analysis of the rich video data, we adapted Ash's (2007) methodology of three different levels: macro, intermediate, and micro. The macro-level analysis aimed at creating a flow chart of all design activities. We coded the video recordings in 3-minute segments with the ELAN multimedia annotator. The theory-driven coding template was developed for characterizing the collaborative design and making processes. This template was developed for the larger research project, and used for all video data of the project (Riikonen, Seitamaa-Hakkarainen, & Hakkarainen, 2018). The coding template and codes focused on a) the main verbal actions (for example, seeking information, process organizing, ideation, evaluation, redefining the idea); b) embodied actions (i.e., drawing, model making, material experimentation); c) non-task-related action; d) nature of collaboration within the teams. Due to the iterative and cyclical nature of a design process, different phases of ideation and idea refinement appeared simultaneously with prototyping. The coding process ensured systematic management of the video data, and the visual process rug (figure 2) provided a brief representation of the design sessions, as well as context for more detailed levels of analysis. The process rug, together with multiple viewings of the video data, informed the next, intermediate level of analysis, which focused on choosing and describing "significant events."

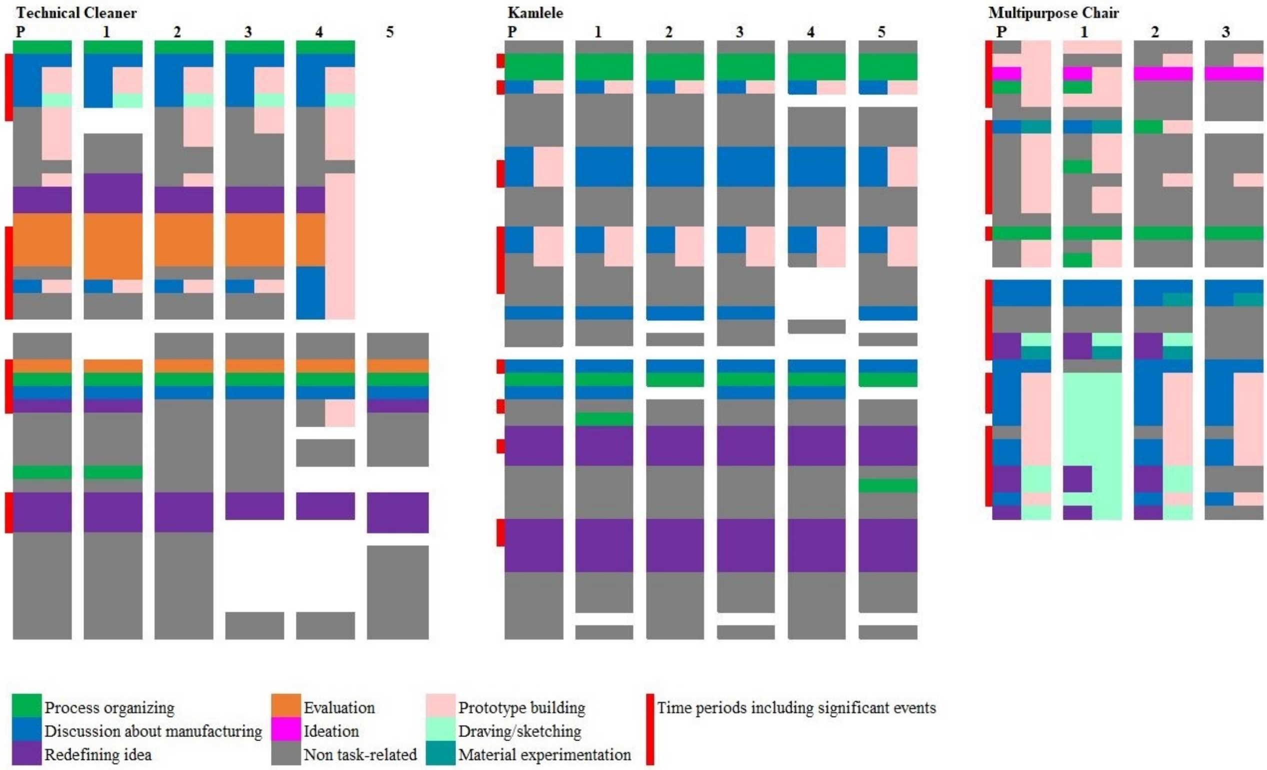

Figure 2. Process rugs of the two sessions. P = teams' primary design actions, 1...n = actions of individual team members

In the present study, significant events presented prototyping actions, such as a team member explaining his/her idea to others while using the prototype as a representation. Figure 2 presents the design activities of the prototyping sessions of each team, and the time periods where the prototype appeared significantly (red columns in figure 2). Besides building, pupils used the prototype during process organization, discussions about manufacturing, evaluation, and refinement of the idea. The intermediate level analysis was divided into two phases: identifying all significant events and then selecting representative events for micro-level analysis. We identified 41 significant events according to the following criteria:

(1) The event had a clear beginning and ending
(2) The event was continuous
(3) The event included some of the following embodied or verbal prototyping actions:
  a) prototype was used during ideation,
  b) prototype appeared as a social mediator,
  c) prototype emerged as a material constraint

The first two criteria directly follow Ash's (2007) methodology; the third criterion was based on the theoretical background of the study. A time period including significant events (Figure 2), often comprised multiple successive events, each presenting different prototyping roles. The 41 significant events identified lasted from 20 seconds to a few minutes. The length of a significant event was not bound to the three-minute segments but followed the natural duration of the event itself, according to the first two criteria described above. We wrote a short description of each significant event and selected 16 events for the micro-level analysis. These events represented the three perspectives of the third criterion described above: prototype appearing in ideation, as a social mediator, and as a constraint. When similar prototyping actions recurred in multiple significant events, we chose only one or two representative examples and excluded the other events.

The micro-level analysis of the 16 events focused on details such as gestures, material manipulation, and verbalization of ideas. We created transcripts including verbal dialogue and rough descriptions of simultaneous embodied actions. The transcripts were analyzed alongside the video clips to ensure that the diversity of embodiment would not be lost in the limitations of verbal description. We categorized different types of actions under two foci that emerged from the data. Focus was either on actions related to ideation, or actions related to working. The foci were further classified into various categories. Table 2 presents the perspectives, foci and categories of intermediate and micro level of analyses.

Table 2. The perspectives, foci, and categories of intermediate and micro-level analyses

Perspectives	Foci	Categories
Prototype as an aid for thinking	Ideation: Idea refinement	Evaluating the physical representation of the idea Material experiments for refining structures Prototype involved in ideation conversation
	Working: Prototype refinement	Prototype-building practicalities Choices based on material feedback
Prototype as social mediator	Ideation: Idea verbalization	Presentation of existing idea
	Working: Teamwork	Division of labor Prototype as a focal point
Prototype as material constraint and inspiration	Ideation: Design constraints	Material design constraints
	Working: Material practicalities	Playing around Slow progress Rough appearance

In this study, the three levels together offer a comprehensive overview of the roles of prototyping in elementary students' collaborative designing. We used the levels to provide different viewpoints: when (macro), what (intermediate), and how (micro). For example, a prototype appears during ideation conversation (macro) as a support for verbalizing an idea (intermediate), during which a pupil points to the prototype, and manipulates it to demonstrate a vague verbal expression "like this" (micro). In the following, the findings presented are mainly related to the micro-level of analysis, however, the macro- and intermediate-levels provided a broader context for the detailed description of activities.

Findings

Prototypes as aids for thinking

Prototypes appeared as aids for thinking while the pupils were either refining their ideas or the prototype itself. Idea refinement included evaluation of the physical representation of the idea, material experiments for refining structures, and prototype involved in ideation conversation. Prototype refinement included prototype-building issues and choices that were made based on material feedback.

All teams refined their ideas by evaluating the prototype, which acted as a physical representation of the design idea. Kamlele and Technical Cleaner groups built box-shaped prototypes. The Technical Cleaner group's prototype shape was based on a sketch that the team drew without accurate three dimensional measurements. The size and dimensions of the prototype surprised the pupils, and they commented that the prototype did not look like it was supposed to. The team decided that the final artifact should be wider and thinner. These concrete suggestions for refining the shape of their invention were based on evaluating the prototype.

Prototypes were actively present in the conversations featuring collaborative ideation. When the Kamlele group was ideating how the invention could be attached to household items, they shared their ideas while interacting with the prototype using gestures and words. For example, pupils pointed at the planned place of the attachment method (Figure 3); lifted the prototype against the wall to enact the positioning of the device; and demonstrated missing elements, such as hooks or suction cups, with gestures.

Extract 1.

Caroline [*grabs the prototype*]: I was thinking [*points to a side of the prototype*] that it could be like this here…like this would be entirely magnetic.
[*Points towards the table and twirls her finger*] Then there would be a small bag where there would be, for example, four suction cups.
[*Forms a cup with her hands and takes her hands to the prototype. Taps the imagined point of attachment with her finger*] And then on the other side of the suction cups, there would be another magnet, and then those could be like fastened there.

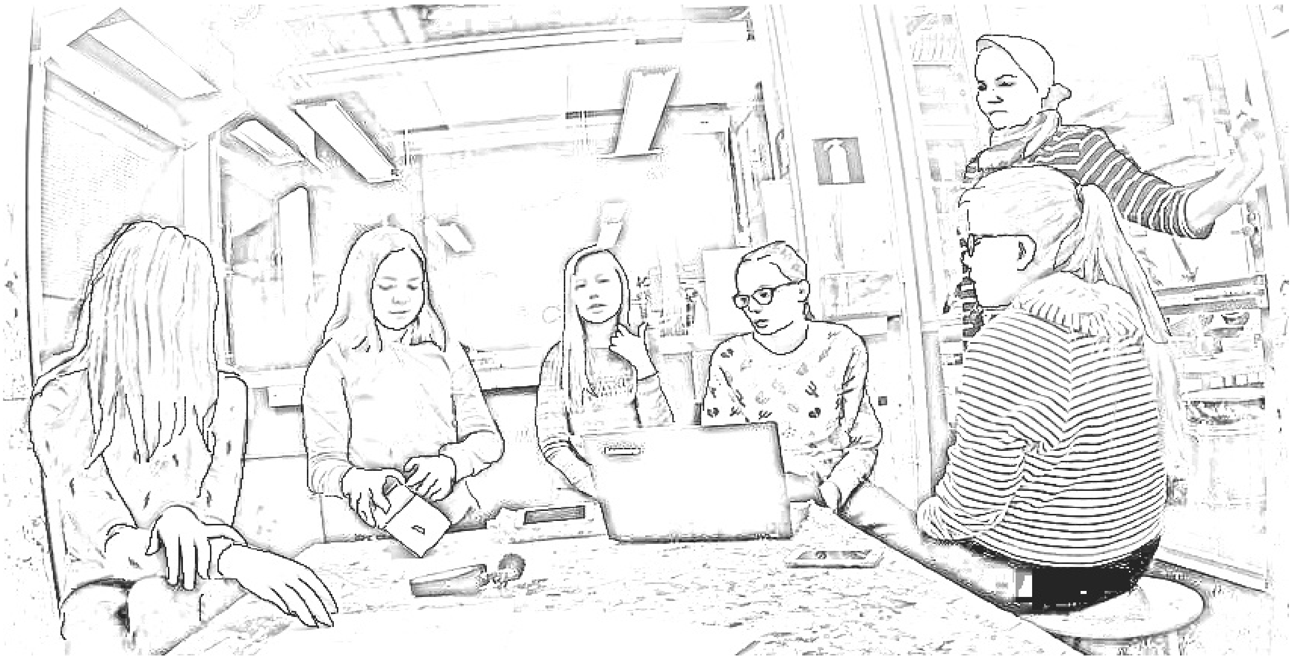

Figure 3. A Kamlele pupil pointing to the prototype during one of the team's ideation

The Technical Cleaner group was interacting with the prototype while ideating the digital features of the artifact. The teacher asked about the function of a certain piece in the prototype, and the team first told him that it served just for aesthetic purposes. But during the conversation, which involved gesturing to the prototype and passing the prototype around, they came up with a new idea: the piece in question could be a display with digital functions. Hence, verbalization of ideas appeared simultaneously with ideation.

The prototype of the Multipurpose Chair had some mechanical structures, such as its folding hood. A pupil had built a small prototype of the hood; when evaluating it with the teacher, the team agreed that some changes needed to be made. First the pupil, by himself, silently and slowly moved his finger across the prototype. Then, he unraveled the prototype and started to build the new hood. He took one piece at a time in his hands, twisted and turned it, tested different ways to place it, then glued the piece in. The mechanics of the new hood was based on the teacher's vague suggestion, but the pupil found the exact solution through material manipulation. Later, another pupil from the Multipurpose Chair group came up with the idea of a foldable leg rest when absent-mindedly twisting a play dough model of the chair. In these situations, the embodied thinking, ideation, and manipulation of materials appeared simultaneously.

The teams' main focus in the selected design sessions was prototype building. The issues relating to the prototype were discussed more than those relating to the designed artifact. Teams used physical materials for testing the structures of the prototype before making decisions and decided measurements with materials. For example, pupils from the Kamlele and Multipurpose Chair groups manipulated the pieces of their prototype and tried to construct them in different ways before gluing them together. A pupil from the Technical Cleaner group determined the size of a camera based on material manipulation. She took some play dough in her hand, looked at it, and then added some more play dough. Next, the team decided the size of their prototype by placing the play dough camera on a plastic board and drawing a rectangle around it. None of the three teams made detailed plans for building the prototype. Instead, when a problem occurred during building, pupils rather used immediate material feedback to solve it.

Prototypes as social mediators

Prototypes appeared as social mediators to support pupils' teamwork and the verbalization of their ideas. During ideation, the prototypes were used for verbalization of existing ideas. During teamwork, the prototype was involved in the division of labor and acted as a focal point.

When pupils presented their existing ideas to others, they used the prototype as an aid for verbalization. For example, a pupil from the Multipurpose Chair group presented their idea to a teacher with words like "this way," "here," "like that." However, he supported those vague expressions by gesturing to the prototype and manipulating it. The Technical Cleaner group used their low-fi prototype for presenting digital ideas to the teacher. They pointed to the prototype when explaining planned digital functions. In the Multipurpose Chair group, one pupil said he did not understand the team's idea well enough to participate in the construction. The two other pupils utilized a sketch and a prototype as aids for explaining their idea (Figure 4). Pupils pointed to the sketch and then to the comparable structure of the prototype, manipulated the prototype, and referred to the prototype with verbal expressions. Here, the prototype assisted in creating a common ground for the teams' understanding of their idea in development.

Extract 2.

David [*Points at the sketch*]: Look, there is the chair, here are the retainers
John [*Comes along. Points at the sketch.*]: Look. Here is the bottom of the chair, this is the chair itself. Look, it is…. Where is the actual prototype? Here! [*Reaches for prototype.*]
Michael: Is it a little like a sun... umm, sun thing…
John [*Points at the sketch and the prototype in turn.*]: Look, these are like this part. This is this part. This is the bottom thing. [*Draws with his finger on the prototype.*] And then it has this hood on top. [*Grabs the hood and sets it on top of the chair.*]
Michael: Yeah, I get it

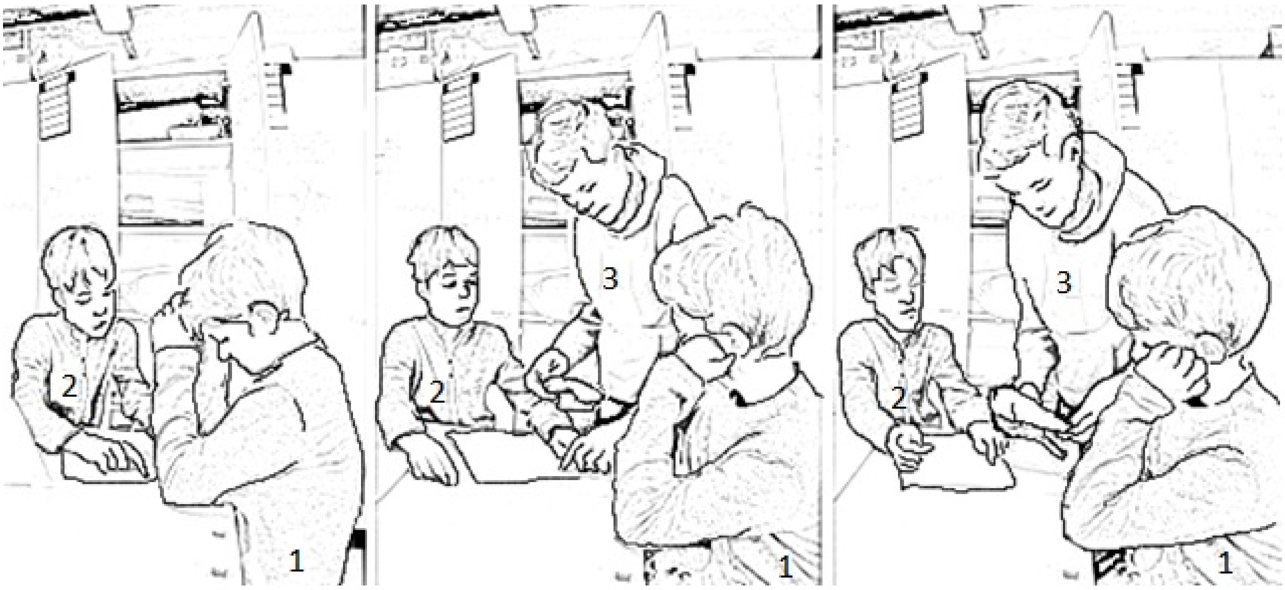

Figure 4. Multipurpose Chair pupils (David (2) and John (3)) explaining their idea to a team member (Michael (1)) with a sketch and a prototype

In many cases, the prototype was a focal point for the team. For example, a pupil in the Kamlele group was building the prototype and others were talking about off-task topics. But when the pieces of the prototype did not seem to fit together, everyone turned their attention to the prototype. The team started to consider possible solutions together, and when one pupil presented her idea, she simultaneously demonstrated it with the prototype. In some cases, team members also used the prototype to emphasize their turn to speak. For example, when a pupil in the Technical Cleaner group wanted to present his idea, he took the prototype and waved it in the air demanding attention. When he finally got the floor, he presented the idea by drawing an imaginary display with his finger on the prototype. Similarly, when the Kamlele group was ideating the attachment method together with the teacher, the pupil who wanted to speak snatched the prototype for herself.

An uneven division of labor occurred in all the groups. Often, only one pupil was building the prototype while others were playing around or doing some off-task actions. For example, in the Multipurpose Chair group, one of the pupils was building the prototype by himself, and also developing the idea alone. When other pupils asked for something to do, they got only some assisting jobs, for example, to bring some materials or make the glue gun ready. Also, in Technical Cleaner group one pupil took the main responsibility for building the prototype. Nonetheless, unlike in the Multipurpose Chair group, all members of the Technical Cleaner group participated on ideation during prototyping. Pupils followed the construction process closely, commented on the pivotal phases, and suggested solutions. Collaboration occurred even when there were not enough tasks for everyone in building of the simple prototype

However, from time to time teams did find ways to engage everyone in the construction. During those moments, the construction task was divided into smaller tasks. For example, the Technical Cleaner group divided the labor between four pupils, so that one pupil made the buttons from play dough, two pupils cut walls from foam board, and one pupil wrote the presentation on the computer. The division of labor was not decided verbally, but by taking control of the equipment or materials needed for a task. Even when pupils had their own tasks, they did not work in isolation but commented on each other’s work. For example, the whole Technical Cleaner group reflected together on how they could draw a rectangle with a single ruler. The material issues of the prototype created possibilities for combining the divided work.

Prototypes as material constraints and inspiration

Prototypes as material constraints appeared in the design process when pupils evaluated design constraints related to materiality. Material constraints also appeared in practicalities, for example through the slow progression of work or rough appearance of a prototype.

Prototypes can be used for evaluating the material constraints of the designed artifact. However, in this study, teams discussed material constraints only twice. For example, two pupils in the Multipurpose Chair group reflected on the footrest of the chair. One team member suggested that the rest could come out from under the chair. By testing the suggestion with the prototype, the other pupil concluded that there was not enough space. Similarly, Technical Cleaner group had decided that the artifact should be thinner, but one pupil questioned whether the planned display would fit in the thinner device. A pupil then tested the size of the display on the prototype with gestures (Figure 5).

Extract 3.

Ted: So, how will the display fit in there, if…
Stina [*Lifts the prototype and sets her hand in the middle of the prototype*.]: Then it comes to… Because now there is only this much. So it will fit. [*Demonstrates the size of an imaginary display with her fingers and moves them upwards*] If we take half off, then this only moves up there and it is its… [*Moves her finger across the prototype*] And it can in this order, that time, place…
Ted: Yeah

Figure 5. A member of the Technical Cleaner team demonstrating the size of a planned display in relation to the prototype

Material qualities of the prototype affected the work; pupils played around with materials and made sensory observations. In this study, these observations focused on the prototype, not on the materials of the designed artifact. For example, the Technical Cleaner group marveled at the smell and stickiness of play dough, a material solely used for prototyping. A pupil in the Kamlele group sanded a piece of plastic board, a prototyping material, and noticed that the piece heated up. The whole team got excited and everyone wanted to try the hot plastic board themselves. Moreover, off-task playing with the materials occurred, for instance, when pupils built funny figurines from play dough, made a smartphone appear to be broken with stripes of hot glue, and found different ways to twirl bubble wrap around a finger. Materials invited pupils to play and inquire, but, here, this excitement was not notably task-related.

The slow progress puzzled pupils. During these recorded sessions, all three teams commented on how little they had managed to accomplish. As the process rug (figure 2) demonstrates, especially the second design session of Technical cleaner and Kamlele teams included plenty of off-task activities. Teams did not use materials requiring slow craft techniques. Two of the teams even built a very simple prototype: a box. Yet, one reason for slowness appeared to be that the pupils did not have enough craft skills to manipulate the materials or to use the tools. For instance, the Kamlele group had to wait for the teacher for a long while when the glue gun was not working. In the Multipurpose Chair group, two pupils had trouble sawing a board, and were just about to quit altogether, when a teacher arrived to provide an example. At this stage, manipulating the materials, the teachers' support was essential to the teams' progress.

The appearance of the prototypes in this study was rather rough. Pupils reacted to the appearance with laughter. They bemoaned: "that looks stupid," "this looks like a washing machine," "yuck" and "that is so ugly." The Multipurpose Chair group was the only team that built a second, more attractive, version of their prototype. In their case, even the teacher commented that the first version was ugly. The pupils evaluated the second version as a "bit weird but OK." In the Multipurpose Chair group, one of the pupils made a virtual model of the chair. All conversations about the virtual model concerned the appearance of the chair, which the team members admired the in the virtual model. Their material prototype focused more on the structure and mechanics of the artifact.

Discussion

In the present study, we investigated the role of prototyping and material model making in elementary school pupils' collaborative design process. We examined how the prototypes were used as an aid for thinking or as social mediators, and how they functioned both as constraints and inspiration in the process. In this section, we present opportunities and challenges related to the three perspectives, as well as provide concluding remarks.

The prototypes were used as *aids for thinking*, mainly for refining the prototype itself but also for developing the design ideas. The teams used the prototype for evaluating features of the artifact, which supported pupils in making concrete refinement suggestions. For instance, the Kamlele and Technical Cleaner groups focused on the shape and size of the artifact; pupils compared the prototype to their original idea and presented some concrete suggestions for refining the shape. The Multipurpose Chair group used the prototype for evaluating the structure and structural functions of the artifact, testing their ideas by manipulating the prototype. In the present study, the teams discussed more the practical issues concerning the prototype than, for example, the material design constraints of the designed artifact. Previous studies (e.g. Kangas et al., 2013a; Looijenga, Kalpwijk & De Vries, 2015; Welch, 1998) have shown that a concrete and tangible prototype can aid elementary school pupils in evaluating their ideas. Furthermore, embodied thinking (e.g. Groth, 2017) was revealed while pupils were working with the prototype. They tested structural options before gluing the prototype together. During collaborative ideation, the prototype was indicated and “expanded” with gestures.

The three-dimensional prototype aided pupils in perceiving the shape and dimensions of the artifact; mere two-dimensional sketches had not provided them with adequate understanding of the three-dimensional shape. For example, the Technical Cleaner team was surprised by the shape of their prototype, after building it according to a two-dimensional sketch. Kangas et al. (2013b) have discovered similar benefits of three-dimensional prototyping. Williams and Sutton (2011) emphasized the importance of spatial reasoning for adult designers, including the ability to imagine 3D shapes from a 2D presentation. Furthermore, pupils should learn how to plan, model, test and iterate solutions by moving repeatedly between 2D and 3D models. These iterations would inspire mental visualization and support spatial skills (Riley, 2016, 21).

When verbalizing abstract ideas and presenting their plans, pupils used the prototype as *a social mediator*. When new ideas were proposed, old ideas were refined, or the existing idea was presented, pupils referred to the prototype with words and gestures, such as pointing. Illum and Johansson (2012) have emphasized that material representation supports the verbalization of abstract ideas (see also Kangas, 2013a; 2013b; Welch, 1998). In this study, the prototype also supported the collaboration by gathering attention. Pupils utilized the prototype when they wanted everyone to listen: they snatched the prototype or waved it around. Rowell (2002) pointed out that physical materials stimulate collaboration. In this study, practical issues with building demanded collaboration: when a problem occurred, groups’ diffused attention came to focus on the prototype

In the present study, the division of work between team members was often uneven. Pupils did not find prototype-building tasks for everybody, so some pupils spent a major part of the sessions idle, engaging in actions unrelated to the task. For example, in the Multipurpose Chair group only one pupil took the lead, and two others were left somewhat as outsiders. Two other groups aimed to divide the work more evenly by dividing the building project into smaller tasks; however, this was not always possible because of the simplicity of the prototype. Clapp et al. (2016) emphasized the importance of participation in collaboration. They also posit the view that a limited amount of materials might result in pupils having to consider, for example, sharing and other practical aspects of collaboration.

The prototypes also acted as *constraints and inspiration to the process*. Young pupils do not have the same fine motor skills, material knowledge, and craft skills as adults. In this study, the lack of these skills appeared as challenges in simple building tasks. Pupils seemed to get frustrated with the slowness of the work. They commented on what little progress they made during the sessions. Welch (2000) described material prototyping as naturally slower than sketching. The slowness of physical prototypes has been pointed out in studies in industrial design (Ramduny-Ellis, 2010) and design studies (Vrencoska, 2013). In this study, pupils found it challenging to work with even simple materials and tools. These challenges alongside the uneven division of labor probably accounted for some of the slow progress. Materials and techniques used for the prototype were simple and basic, and so were the pupils’ craft skills. As a result, the appearance of the prototype was rough. The appearance provoked laughs and headshakes among the pupils and even a teacher. Pupils said out loud that the prototype does not look the way it should. Without the technical skills to manipulate materials into the desired form, it is difficult to materialize an idea. Groth (2016) emphasized that even among adult designers insufficient skills in material manipulation can result in frustration throughout the entire design process.

Welch (1998) pointed out that children have natural experience with building and designing through play. Concrete materials could stimulate playfulness: in this study pupils played with the materials but the play was usually not task related. Nevertheless, pupils were visibly excited by the heat created by sandpaper, the gooey feel of the modelling clay or the funny little figures they made with play dough. Steering this enthusiasm for play towards the task at hand is a question that should be noted in elementary school design teaching.

To conclude, we can say that the material prototype had a rich and versatile role in the collaborative design process. The prototype was in active use when pupils were building it, but also during process organization, discussions about manufacturing, ideation conversations, evaluation, and refinement of the idea. In this study, some characteristic features of prototyping in elementary school appeared. These include young pupils' skills in spatial reasoning and craft techniques, and their tendency towards playfulness. The prototype was instrumental in collaboration and it was used for supporting the verbalization and refinement of ideas. The prototype was also used for testing the structure of the artifact and it aided pupils in determining its three-dimensional shape and dimensions. However, some challenges in working with the prototype also appeared. The work was slow, the division of labor uneven, and the appearance of the prototype was mainly just amusing. Nevertheless, this study suggests that prototyping has potential in elementary school projects.

Conclusions

The findings of the present study provide grounds for the pedagogical and theoretical implications of the role of prototyping in elementary students' collaborative design process.

Building a material representation of an idea is a broad task. Binder et al. (2011) argued that a prototype can focus on several details and have multiple goals, and that professional designers usually create several contemporaneous prototypes. It is no surprise that elementary school pupils might have difficulties comprehending the purpose of the prototype. According to Klapwijk and Rodewijk (2018), even though young pupils often need teachers' support in selecting the prototyping goal, pupils can learn to develop specific sub-goals for their prototype building. In the present study, the prototyping task did not have a specific goal and it became evident that while building the prototype, pupils' attention and design actions focused mainly on the prototype itself and not on developing their design ideas.

Also, time was an issue in the present study. Pupils tried to build their whole idea in a relevantly short time period with limited resources and skills. Constraining the task could help pupils to focus on only selected, relevant questions, relating to, for example shape, mechanical function, or appearance. Klapwijk and Rodewijk (2018) emphasize the importance of very specific prototyping goals, in order to help pupils to ignore other, currently irrelevant, goals. Also, focusing on some details could give time for iteration. Clapp et al. (2016) emphasized the importance of iteration for refinement of the idea (see also Looijenga et al., 2015; Welch, 1998). In this study, only the

Multipurpose Chair group had time to build a second version of their prototype. Other groups also had refinement ideas, but they did not have time for iteration.

Young pupils do not necessarily comprehend the range of possibilities that the prototype offers, as expert designers do. Kangas et al. (2013a) stated that the prototype can easily take on a more dominant role than the designed artifact in elementary school settings, as was the case in the present study. Therefore, the role of the prototype as a tool should be made explicit. Adult designer utilize the prototype, for instace, for testing structural or visual details (Binder et al., 2011) or by visualizing the idea when presenting it (Ramduny-Ellis et al., 2010). Similarly, Binder et al. (2011) have pointed out that the main focus of designing should be on the designed artifact, and the prototype is merely a medium for connecting with the artifact.

Physical materials bring along practical issues. Clapp et al. (2016) pointed out that prototyping with physical materials can be messy and complex; consequently, it is especially important to pay attention to the organization of the materials and the classroom. Prototyping and, therefore, the whole design process in this study was occasionally hindered because of practical issues, such as missing tape or a broken glue gun. Another practical challenge was the young pupils' lack of craft skills. In this study, teachers chose simple materials and simple techniques. On the other hand, Clapp et al. (2016) argued that high quality materials and professional tools could be important for learning and motivation. Finding motivating high quality materials and techniques that suit the skills of the pupils requires craft experience and material knowledge from the teacher. Ramduny-Ellis (2010) argued that the possibilities of the material are more dependent on the skills of the user than on the choice of the material. In an elementary school setting, teachers' ideas and examples could fill the gaps in pupils' skills. Craft skills could also be taught either beforehand or during the process by, for example, peer-to-peer tutoring.

To conclude, material prototyping needs some special attention from the teacher, when designing the task and planning the project. Clear goals and a reasonable level of constraint could help focus attention on the designed artifact and avert attention from irrelevant qualities of the prototype. Practical issues need to be considered in order to make prototyping sessions flow smoothly. Pupils craft skills should be noted when designing the task and choosing the materials.

Further research is needed in order to implement the tentative results of this study in practice. To gain a more profound understanding of the phenomenon, various projects led by different teachers with a wide age-range of pupils should be studied. An interesting next step for study could be an investigation into how to bridge the gap between modern digital technologies and traditional craft techniques. In this study, small glimpses of simultaneous development of material and digital prototype appeared: material prototype modelled structures and digital prototype presented aesthetics. When studying the possibilities of digital prototyping, the unique qualities of materiality should not be forgotten.

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Considering the relationship between research and practice in technology education: A perspective on future research endeavours

Niall Seery, Athlone Institute of Technology, Ireland

Richard Kimbell, Goldsmiths, University of London, UK

Jeffrey Buckley, Athlone Institute of Technology, Ireland & KTH, Stockholm Sweden

Joseph Phelan, University of Nebraska, Lincoln, USA

Abstract

Technology subjects are a relatively recent addition to the discipline offerings at post-primary level, and have a short but interesting history in terms of associated educational research. In this paper, an overview of the evolving research agendas that emerged in response to the nature of practice, from the perspectives of the Technology Education Research Unit (TERU) and the Technology Education Research Group (TERG) is presented. A chronological account of their research activities is provided, demonstrating the perspectives, paradigms and foundations of their research endeavours. The purpose of this paper is to provoke reflection on the past, present and future of technology education research and practice, using both TERG and TERU for narrative purposes. Therefore, this paper concludes by sharing the evolution of research in TERU and TERG, so as to help consider and shape the future of relevant, contemporary, and progressive research activity.

Keywords

technology education research, Design and Technology education research, TERU, TERG

Introduction

Of the many different perspectives taken within technology education research, the majority share the same agenda of enhancing teaching and learning practices within the field. Despite the volume of effort being invested into this endeavour, there are substantial differences in the status achieved by the subject(s) internationally (Wright et al., 2018). For example, in some countries such as Ireland and Sweden, educational reforms are seeing an elevated status being granted to technology subjects through the development of new syllabi or through additional time allocation, while in other countries, such as the UK and South Africa, current reforms are indicative of a decline in the status of technology subjects as they are being integrated or dissolved into the natural sciences. The fact that technology education is suffering a reduction of status in some countries is an outcome of the problem that, as a subject area, it is not clearly conceptualised and its utility is not coherently evidenced, which has resulted in a variety of interpretations of its efficacy within general education. Technology education research needs to respond to the discourse within this currently divisive climate but in order to do this effectively, it is paramount that new agendas can empathise this climate. Therefore, this article uses 'Technology' as a universal international description, that is respectful of the individual cultures, conditions, and curricula that define the specific contexts for individual subjects, and 'Design and Technology' (D&T) on occasion when making specific reference to the UK curriculum.

To understand why so many interpretations currently exist regarding the utility of technology education, and to contextualise future research endeavours, it is necessary to consider how it is positioned as a subject area in national curricula at the moment. To understand this, it is useful to consider how it has changed over time. Technology curricula in most countries have strong vocational origins and traditionally focussed on training explicit remits of craft skills. While the nature of the craft in terms of core materials, knowledge and skills could vary, expertise was visible and clearly demonstrable. Contemporary technology education has evolved to now espouse a more comprehensive view of craft and making such that aspirations of the subject now also include the development of more ambiguous competences such as technological capability (Gibson, 2008), technological literacy (Williams, 2009), and technological perspective (Barlex, 2000). This ambiguity and subjectivity have resulted in a large degree of variance and uncertainty within D&T practices (Kimbell, Stables, & Green, 1996) as while educators may share similar aspirations to develop these capacities there can be considerable differences in the pedagogical approaches which are used (Atkinson, 2017). Stemming from this, Technology as a subject area is regularly described as not having an explicit epistemological boundary and instead having a fluid treatment of specific knowledge in its endeavour to develop students' competences (Buckley, O'Connor, Seery, Hyland, & Canty, 2019; Buckley, Seery, Power, & Phelan, 2018; Kimbell, 2011; Norman, 2017; Williams, 2009). The positive aspects of this include the arguably elevated status now afforded to teachers as they have more autonomy, and the increased capacity of the subjects to cater for societal needs. However negative consequences also exist such as the difficulty in generalising research to practice due to the variability in practice. Additionally, without a clear definition of its goals, evidencing the utility of technology subjects beyond what could be provided by other subjects is difficult and provides a challenge to policy makers to assign value and justify the provision of these subjects. It is for these reasons of having a fluid epistemology, ambiguity of purpose, variable practice and resulting inconsistent stakeholder beliefs that technology education is facing challenges in many countries (e.g. Barlex & Steeg, 2017) and it is the aim of this paper to provide context for addressing these challenges through research on teaching and learning in the area.

To support the inception of new research concentrating on teaching and learning in Technology, this article presents a brief synopsis of the evolution of research conducted by two prominent research groups in D&T education, the Technology Education Research Unit (TERU) and the Technology Education Research Group (TERG). By describing how the activities of these groups responded to the needs of the subject at the respective times, context is given to a current challenge of legitimising the various interpretations of Technology within general education to its external stakeholders. It must be acknowledged, that many earlier initiatives and commentators (largely in the 1970's) shaped the then landscape of the area, particularly in the UK and this formed the foundations of subsequent research activity. Although TERU and TERG are used to exemplify the development in thinking, importantly, there were many other prominent researchers and research groups active during this time who contributed greatly and continue to contribute to contemporary thinking in technology education. The use of TERU and TERG as examples serves purely to guide the narrative of the evolution of technology education research as key moments in the chronology of these groups share parallels with the challenges facing the broader remit of technology education researchers. TERU and TERG were established independently at a time when Technology was transitioning from being a heavily vocational subject to a more general subject. TERU was formally created first in the UK in 1990 and TERG, created in Ireland in 2010, was significantly influenced by the early work of TERU. Importantly, founding members of both TERU and TERG were actively researching in teaching, learning and assessment in Technology prior to their establishment of formal research groups. Initially, research by both TERU and TERG was committed to and heavily influenced by practice orientations and while research was rigorous and impactful, it was not represented or guided by an explicit educational research paradigm. Instead navigating the major research paradigms was an unconscious challenge that relied heavily on practice based experience and personally held beliefs of what was of value in technology education. Both groups operated in different contexts, eras, circumstances, and political landscapes, but were linked mainly by intuitive drivers. Founded two decades apart with very different starting points, the convergence of empirical insights and the identification of key priorities has over the years aligned their interests and agendas. Now, for both groups, research remains heavily influenced by practice, but there is an increased motivation to understand the implications of practice for learners at a more foundational level.

The significance of intuition: The beginning of a journey

Building on the significant discourse surrounding design education in the 1970's, the agenda crystallised with the Assessment of Performance Unit (APU) funded project for D&T in the mid 1980's. The APU project, conducted by researchers who would ultimately become TERU, was a significant milestone in establishing the worldview driving their research activity. The APU was the research branch of the Department of Education and Science (DES) in England. It was designed to answer questions at a systemic level about big-picture units of the education service rather than about individual students or schools. It was designed to provide hard data to assist the policy/planning function for the DES. TERU were commissioned in 1985 to develop the battery of tests in D&T, and following precedent, the expectation was to define the knowledge areas and develop tests for them. However, TERU proposed the idea that it is not exclusively about knowledge in D&T. The position was defended in the initial document which made the case for assessing the process of learning (Kelly, Kimbell, Patterson, Saxton, & Stables, 1987). Here it was argued that there was a need to understand what students could do in response to real design tasks. The inclusion of design challenged the universally understood and accepted epistemology that defined a school subject. The need to understand, acknowledge and celebrate the process was conceived and the intuitive drivers for the shift in knowledge treatment initiated a sequence of challenges. The shift from knowledge tests to focus on a process of design and development was completely original and required a methodological rethink. TERU created the tasks and then developed a way to administer them remotely to 10,000 students (a 2% national sample), most of whom had no prior experience of design within formal education. Background data was also collected on those students allowing for their performance levels and their curricular experience to be equated. The research resulted in the capturing of 20,000 pieces of design performance from which a variety of findings about the impact of curriculum, context, gender and task type were produced (Kimbell, Stables, Wheeler, Wozniak, & Kelly, 1991).

The brief from the APU head office at the DES to 'find out what the nation's 15-year olds can do in D&T' was not original. It had been done previously in Science, Mathematics and for Modern Languages. However, the response of TERU was original as it did not define D&T as susceptible to explanation through short knowledge tests. TERU defined it as a process and then established methods to make it possible to assess that process. The collected data from this research resulted in the iterative model depicting the relationship between mind and hand (Kelly et al., 1987). The model proved capable of describing the performances observed and demonstrated that in D&T the most reliable form of assessment is holistic.

The results of this project framed the next stage of enquiry. The APU project explained practice in a quasi-experimental design, but the question of validity remained. The activities were artificial to the extent that they were based on short pieces of design activity, not real whole tasks. With strong evidence and a clear agenda, TERU secured funding from Economic and Social Research Council (ESRC) to examine the reality of the process model through case studies. Again, the originality was in the methodology. Driven by the authenticity of the evidence, it was essential to find ways to capture the entirety of the uncertain classroom processes. As a result, TERU developed an observation framework for following four students at a time in a classroom and recording everything they did every 5 minutes for the whole duration of their projects. Research enquiry focused on questions like, who is leading the activity, the teacher or the learner, and what are they doing? After much experimentation and methodological refinement, the approach resulted in 80 (4 students in each of 20 schools) detailed and authentic accounts of D&T performance and learning.

The authenticity of the data created a shift in focus to developing ways of analysing the data. The resulting datamaps were developed to enable the illustration of performance types. Interesting data emerged form that data that they showed how the balance of teacher as director and teacher as supporter varied across school years. The big discrepancy was with Years 7 and 8, the first two years of high school, where teachers were far more directive than the teachers at the top end of primary school. It also made visible girls' performance set against all the different APU test types. This was a complex problem and without the development of the datamaps, it would not have been possible to untangle the significance of the data captured. The data demonstrated that the high ability group performed consistently better than the mid ability group and that the low ability group performed better as the nature of the assessment changed to the point that their performance was almost indistinguishable from the mid ability girls by the end of the assessments. This provided insight about girls' performance in D&T and also about how different tests, tasks and contexts can impact learners' performance in D&T. The possibility that activities could be designed to deliberately favour a particular nominated group became clear. Additionally, it appeared possible to design activities that largely eliminate bias or to at least balance one sort of bias with another, an act which would be of significant importance to educators.

The two projects were conceived as complementary in the sense that since the APU funded project was large scale and produced generalisable findings, the ESRC funded project needed to be small scale and detailed enough to capture and represent authentic performance. Considering both datasets provided for an informed position and emerged a set of theoretical propositions to explain D&T performance including:

- The iterative model was shown to be generalisably valid
- Tasks were shown to operate differently in different contexts
- The context effect was shown to operate as a hierarchy from broad contextual tasks with a frame of reference from within a context to specific tasks from within a frame of reference
- Thematic contexts also have an impact, i.e. where there was a personal context girls performed better, boys performed better when there was an industry context, and an environmental context proved to be more gender neutral
- Beyond context the tasks themselves could be set as open-ended or closed-ended and this affected group differences in performance
- Primary compared to secondary schools operated different models of practice concerning learner autonomy
- Concepts of 'progression' in D&T could be identified and exemplified
- Assessment practice was shown to operate better as holistic rather than as criterion referenced, and this could be rationalised

The iterative model of mind and hand (Kelly et al., 1987) evolved as a distillation of practice and the APU funded project was then a diagnosis both of learners' performance within it and of the behaviour of the instruments that were developed to probe that performance. The ESRC funded project then enabled those diagnostic elements when set within whole authentic activities to explore larger-scale classroom phenomena, such as progression, and for them to be characterised. The predominantly observational approaches of TERU furthered insights into practices by both aiding the conceptualisation of D&T as a subject in general education and, within this new conception, identifying what worked best for learners. This work paved the way for more predictive research which could both aid in refining the concept of D&T in education and identify more explicitly the underlying factors of performance, attitudes and motivation.

Establishing new pathways: Building research capacity

In an attempt to map out the territory, work commenced on pedagogy and assessment. Projects in TERU amounted to a series of controlled experiments designed to transform practice. For example, the Assessing Design Innovation project (Kimbell et al., 2004) focused on creating and structuring tasks to deliberately provoke creative performance. This grew into 'The Innovation Challenge' run by the exam board OCR as one of their GCSE modules in D&T. It then developed into the Advanced Innovation Challenge at A level which is still running (OCR, 2018). This experience resulted in the evolution of the e-scape project to begin liberating digital technologies which made possible a quite different approach to assessment, Adaptive Comparative Judgment (ACJ). ACJ was born out of a recognition for the value of the whole, the rationale for the tasks and the capacity to capture the process of learning authentically and in real-time.

Later and overlapping, as TERU was unpacking the significance of their work, researchers who would ultimately become TERG began the task of independently conceiving a research agenda in the area of technology education. Very much lead by intuition, the early work of TERG focused on macro level thinking with regard to the landscape as it emerged from traditional and vocational influences. Much of the work focused on the ideas and the personal enquiry of people in the group. TERG focused primarily on the development of research capacity and the creation of a supply chain of researchers as this would be needed due to the substantial curricular changes which were occurring. Work on the transition of the discipline area, linked to motivations and interests within the group, formed the foundational position to develop a more applied research focus. The pipeline of researchers enabled a strategic development of the research activities that related to practice but concentrated on external validity. Projects tackled 'big' issues and explored new understandings in context, a context very much influenced by the thinking and work of TERU.

The 'worldview' of TERU had a multi-faceted impact on the development and endeavours of TERG. The outcome of the early work of TERU framed the nature of the process, theorised the core interactions in D&T, and highlighted some of the thematic agendas that warranted further investigation. Working within these thematic areas and others depended on member's individual interests, projects within TERG evolved and built upon each other. As the research capacity increased there was a strategic linking of research agendas so as to build comprehensive insight. The dominant strands were qualified by research in attitudes and interests, pedagogy and assessment, and cognition, with much overlap.

Due to the ambiguity in articulating the vocational, neo-vocational or general educational merits of the discipline area, TERG set to establish an understanding of the current learning and the purpose of learning within the discipline of Technology. Research initially attempted to contextualise and explain the variance in training and education at a macro level and highlighted the need to fully understand the meaning of education when translated to educational tasks and activities. This initial work helped articulate a clear position on what contemporary provision should look like. The epistemological position enabled an exploration of the influences on performance and resulted in a predictive model for the academic performance of engineering students (Lynch, 2009). Interest inventories coupled with second level performance established student-course alignment and could confidently predict future success. Questions then emerged with respect to curriculum design, educational interventions and learners' attitudes towards learning (Dunbar, 2010). The early work of TERG also afforded the opportunity to engage with external moderation and as a result it built confidence in the intent and direction of their 'worldview' as applied to technology education research. At this juncture, the newly developing research capability of TERG, strategically interfaced with TERU and the following phase of work in both groups was largely open-minded enquiry into poorly understood territory. An investigation into the application of ACJ in teaching and learning strengthened the TERU/TERG collaboration beginning through the work of Canty (2012) which investigated the impact of ACJ on student learning. Work at TERG then focused on the idea of supporting discourse in D&T through technology mediated interactions through the PhD work of O'Connor (2016) which critically combined all the existing knowledge and experience built from the initial APU project. Simultaneously, TERG worked on a number of projects that focused on cognition and learning specifically based around modelling and influenced by the iterative dialectic model proposed by TERU. TERG committed significantly to foundational research in the newly defined context of technology (through design) education. Such work explored sketching (Lane, 2011), heuristics (Buckley, Seery, & Canty, 2017; Spillane, 2014), problem solving (Delahunty, 2014) and spatial cognition (Buckley, 2018) as they apply to practice.

Contemporary challenges in D&T: Where to next?

The previous sections, using the evolution of TERU and TERG for narrative purposes, have described some of the chronology of technology education (including the context of D&T) research that has brought the field to where it is now. There is an understanding that the dominant classroom activity is design, and through the use of ACJ there is a valid and reliable tool capable of assessing performance in terms of product outcomes and design processes. Much is understood about creating design challenges for students in terms of the context effect, and about how students should articulate their design journeys through portfolios, building on our understanding of the nature of discourse, communication, and behaviours as they manifest in Technology. Additionally, as a field, there is significant research capacity to address future concerns. Current research effort needs to be invested in uncovering the problems faced by Technology practice today and finding ways to address them. As previously described, there are many beliefs regarding the utility of Technology as a general education subject with the result of this being international variance in its status. This needs to be addressed and will require providing clear evidence that Technology has a positive effect on students. However, in order to achieve this, coherency regarding Technology (all contextual variations) needs to be established. It is argued that this will predominantly involve addressing two areas; the ambiguity of Technology aims, i.e., technological capability and literacy, and what is the purpose and effect of using design to meet these aims.

In terms of the aims of the subject, achieving more coherency regarding what it means to be technologically capable or literate is only the beginning of the solution. There are multiple models for each of these (e.g. Black & Harrison, 1985; Gibson, 2008; Ingerman & Collier-Reed, 2011; Williams, 2009) due to the difficulty in defining them (Gagel, 2004), and there are multiple interpretations of these models, such as considering them to be describing knowledge types rather than a broader form of capability or literacy (Buckley et al., 2018; Pool, Reitsma, & Mentz, 2013; Rauscher, 2011; Underwood & Stiller, 2014). These models suffer the same limitations of other difficult to define constructs. For example, the construct of intelligence is contentious and difficult to ascribe a verbal definition to. In terms of intelligence, Meehl (2006) notes that verbal definitions have never been adequate or achieved a consensus, but the work of Carroll (1993) and Jensen (1998) provided a solution to this problem. The solution here was to provide empirical rather than verbal definitions for intelligence which consisted of factor structures describing the components of intelligence that could be explicitly measured and which had practical use or validity. This approach would likely be appropriate for describing the ultimate goals of Technology. There are models for technological capability and literacy, but these have limitations such as not commanding consensus, having ambiguous verbal components, and having components which are too broad to measure. It would be advantageous to create an internationally agreed upon model which has hierarchical levels of specificity either in terms of definition or context, and where the components can be measured validly and reliably to determine their utility for students in relation to both Technology and beyond it.

Considering design as the dominant activity used to support learning brings further difficulty legitimising the subject. While it is clear that being able to design is of significant importance, it is the manifestation of this within a classroom that requires continued discussion. One of the major elements of this discussion is whether, within Technology, we are teaching to design or through design (with varying degrees of complexity depending on curriculum). If the goal is teaching students to design, what does this mean? To be able to design is an innate capability (Stables, 2008) and could be regarded as a biologically primary activity (Geary, 2007, 2008), that is humans have evolved to be able to design and as a general capacity, like problem solving, it cannot be taught. However, much like problem solving, when a context is applied, e.g., engineering problem solving or engineering design, these capabilities become biologically secondary activity and can be taught. This creates the question, within Technology practice is design considered in general and if so what is actually being taught, or is there a context and if so what is the context, what context specific design skills are being taught and do these have practical utility to students?

In addition to teaching to design, teaching through design is an idea that requires further exploration. D&T education is often described as containing a substantial degree of uncertainty (e.g. Kimbell, 2011) due to the presence of design. Discourse surrounding knowledge suggests that within Technology it has qualities such as being normative, context specific, and applied (de Vries, 2016) and that acquiring it outside of a context is not important (Williams, 2009). The big question is, what does the uncertainty describe? Who is uncertain? It is one thing for Technology students to be uncertain, that is a necessary prerequisite for learning to occur. It is another thing for teachers to be uncertain in terms of knowledge acquisition and learning objectives. For example, students may be engaging in a design task where there is a learning objective concerning craft, or acquiring a specific piece of knowledge. If the teacher is uncertain that the students will engage with the craft process or piece of knowledge central to the learning objective, the design activity may not lead to the desired result. Therefore, the teacher may be uncertain about much of the activity and auxiliary knowledge and skills encountered and used, but there should be absolute certainty that the use of design will allow learning objectives to be achieved. Additional discourse around design suggests that it creates an opportunity for students to learn to apply knowledge. In any design activity students will have to apply knowledge. The question remains though, if this a skill that can be improved? Can a student become better at applying knowledge, and what does this actually mean?

Conclusion

Capturing the importance of the intuitive drivers that created the 'worldview' of technology education, the early years of TERU research was directly seeking to explore and understand the practice of teaching and learning in design & technology. As if to underline this priority, at the end of the first decade of TERU research, resulted in the publication of 'Understanding practice in design & technology', summarising the significance of that decade of research for teachers and schools. Thereafter, priorities shifted.

It is one thing to describe learners' performance, and seek to provide an explanation of it by reference to the nature of design practice, or of the task, or perhaps by reference to the learners' gender. These external, observable variables had been the focus of early TERU research. But it is a completely different thing to seek to explain the idiosyncrasies of individual performance in terms of learners' foundational qualities. Why do certain tasks have certain effects on specific students? These effects are driven by inner qualities of the individual that are less easily observed, and these began to take centre ground in TERG's developing research programme. Inevitably this forced the researchers into quite different research methods and data collection models.

The emerging research agenda concerning the uncertainty of Technology and the treatment of knowledge became more critical and evidence based for two reasons. There is a need to ensure all Technology students receive equitable provision, and because otherwise the subject area will become increasingly at risk of being delegitimised due to a lack of clarity around its aims, functions, treatment, and benefit to students in terms of both within and outside of education.

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