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Editorial
Making, creativity, materiality and making 'specials' more special.

Kay Stables
Lyndon Buck

Welcome to issue 25.2 of the journal. This issue has been prepared at a time when the world is dealing with the challenges of the pandemic created by Covid19 and, like so many things, has required us to work differently and to take on roles that we are not used to. For us, as editors, we have needed to also become a production team – and if this means that the journal doesn't look quite like it has in the past, we hope this can be excused, as we are novices in this respect!

But out of necessity has come what we hope will be seen as a positive step. This issue is a Special Issue, having guest editors who have curated a collection of articles focusing on design and technology in primary education. In recent years, we have combined special and general issues into one issue, and this continues with the current issue. But, while looking for a solution to some practical matters, we realised that we can create Issue 25.2 in two parts Part 1 the general edition and Part 2 the special edition. This means that for the first time, while all articles can still be viewed and downloaded individually, there will be two composite documents, one of which will be entirely dedicated to the special, guest edited section. We see this as an important way of highlighting the value provided by the special edition, and hope that our readers do to. We would be very happy to receive any comments on this.

The Guest Editors, Wendy Fox-Turnbull and Swathi RR, have curated a collection of articles which, collectively, provide insights that include a strong focus on the importance of language and classroom talk in students' learning and also into the influence of cultural norms and behaviours in technology education. The articles also collectively present an international perspective with authors contributing from Australia, Israel, The Netherlands, New Zealand and Sweden. These articles are all introduced in the Guest Editorial in Part 2 of this issue.

Part 1 of this issue is made up of four research articles, a reflection and a book review. Despite the articles coming from authors coming from different national contexts and phases of education, there are interesting threads that run through: creativity, making and materiality.

The first two articles focus on school age learners, the first with nine to twelve year olds, the second with thirteen and fourteen year olds.

The first presents research on the value of hands-on modelling in supporting creative thinking. In *How focus creates engagement in Primary Design and Technology Education: The effect of well-defined tasks and joint presentations on a class of nine to twelve years old pupils,* Annemarie Looijenga, Remke M. Klapwijk and Marc de Vries (Delft University of Technology, The Netherlands) explore building on the Montessori tradition to structure and focus tasks in ways that encourage both spontaneity and freedom when designing. In what could be seen as a counter-intuitive approach they explored using brief, simple tasks, often with a single technique at the core as a way of encouraging freedom to think creatively. Using a case study approach and building on previous research with six to nine year olds they focused on joint presentations early in an activity followed by formative reflection and dialogue that created shared insights and encouraged engagement and the freedom to think creatively. The article is valuable in the ways that it illustrates how pedagogic approaches used with young children can be successfully adapted for use with older learners and how taking a structured iterative approach can increase learners' liberty to be creative.

The second article explores developing pedagogical design in the context of maker-centred learning, including the use of both material and digital practices. In *The development of pedagogical infrastructures in three cycles of maker-centred learning projects*, Sini Marti Riikonen, Kaiju Kangas, Sirpa Kokko, Tiina Korhonen, Kai Hakkarainen and Pirita Seitamaa-Hakkarainen, (University of Helsinki, Finland) took a design based approach to their research and incorporated digital fabrication instruments into more traditional Finish craft classrooms. In doing this, their research explored the impact of a makerspace approach within formal schooling. With some similarities to the research of Looijenga, Kalpwijk and de Vries, they provided structure through pedagogic scaffolding and took a collaborative co-invention approach with the learners to support creativity through design based, maker centred approaches. They also incorporated peer-tutoring. The article provides immense detail in the structure and focus on a three year-long study in one school, revealing how students were engaged in practices of design and machining, and how design tasks, support structures and knowledge resources were scaffolded. The article also details how social infrastructure was created that enabled collaboration and interaction through student team work and team teaching and how materials and technologies were made available. Amongst a set of conclusions, the authors make the following, telling, comment that "According to our experiences, developing maker-centred learning is not dependent on teachers' sophisticated socio-digital competencies, but relies more on the opportunities provided by the curriculum and the schools' structural practices".

Between these first two articles rich insights into how pedagogic approaches for collaborative, iterative, design-based making can enrich learning and creativity in design and technology education.

Linking continues with the third article. In *Material tinkering for design education on waste upcycling*, Carlo Santulli, (Università di Camerino, Italy) and Valentina Rognoli, (Politecnico di Milano, Italy) focus on the importance of understanding materials in design education and provide insight into the range and scope of approaches that expand Nigel Cross's concept of *designerly ways of knowing* to *designerly ways of knowing materials*. In this they refer to, for example, concepts of Materials Driven Design and Materials Experience, alongside the growth of materials libraries, fab labs and maker culture. For their research the focus is on material tinkering, with a particular focus on "DIY materials" - creating and exploring materials derived from waste upcycling. Their research is set in university design schools. Providing a background on the value to students of first-hand experience of such aspects as technical, sensorial, expressive and functional possibilities and potentialities of materials they present the concept of material tinkering and its educational value. They detail a case study of a material experience course with design students that takes a culinary metaphor. Students were encouraged to take a material tinkering approach working with a range of waste materials (such as those with a starch or protein or cellulose base) for students to create what they call a “material demonstrator”. The results of the students’ developments are presented descriptively and visually, showing a broad range of innovative development. The authors also present examples from sources beyond those of the students’ work. They highlight the challenges and problems of the approach, but most importantly they open up the possibilities of taking a very different approach to educating design students through designerly ways of knowing materials.

The final research article in Part 1 is something of a departure from articles the journal typically publishes. It is a scholarly review, with a particular focus on the value of using music as an interdisciplinary approach in a design studio. In *A Literature Review on The Use of Music in Architectural Design Education,* Burcu Ölgen, (Işık University, Turkey) provides a background on research that has focused on using music as a conceptual starting point or inspiration for creative thinking, specifically in the context of architecture studios. Through his scholarly review, we are given insight into a broad range of research into the impact of music in architecture and design studios, showing how music supported students’ imaginations in creating concepts and form and opening up possibilities for this inspiration to be taken further by exploring its value in a range of architectural structures, products, facades and interiors. Across the range of research reported on, different approaches have been taken including using music to inspire the design of instrument forms, as a starting point to express feelings that are transformed into 3 dimensional forms, as a starting point for conceptual design and for a range of three dimensional forms. Commonalities between music and design are noted, through terms such as rhythm, ratio and harmony but the overarching connection between the all of the research reviewed was the impact on students’ creativity.

Beyond the research articles in Part 1 of this issue, we have the regular inclusions of a reflection piece and book review.

The reflection piece in this issue comes from Richard Green, Independent consultant and former CEO of the Design and Technology Association. In an article entitled *A new normal?* he reflects on the current situation in education in the light of the Covid19 pandemic. Focusing predominantly on the situation in England, he places current events in the context of shifts in education policy and practices. He considers both positives and negatives that have emerged over the last several months as alternative approaches to teaching and learning have been devised, adopted and explored. With these in mind he ponders on the question of what will, for better or worse, be the “new Normal”.

Finally, this issue includes a review of a recent edited book published by Sense publishers in their International Technology Education Studies series - *Reflections on Technology for Educational Practitioners.* This collection of fourteen chapters, edited by John Dakers, Jonas Hallström and Marc de Vries is reviewed by Nicolaas Blom (University of Limerick, Ireland). In his introduction, he highlights the in-depth focus on philosophy and the range of perspectives that different philosophers bring to developing understandings in technology education. He provides a descriptive overview of each chapter, concluding his review with a short critique, highlighting what he sees as both strengths and weaknesses and an overall conclusion of the books value through the questions, guidelines and reflections that the chapters collectively present.

Reflection: A New Normal?

Richard Green, Consultant and former CEO of the Design and Technology Association (D&TA)

It seems to me that since the election of the British coalition government in 2010, much of our governing politics has been about looking backwards and extolling the virtues of those 'good old wartime days' that never really existed. This turbo-charged patriotism, or more like jingoism, started with the need for a 'Blitz-spirit' to withstand austerity. Then the Brexit leave campaign was framed around a 'Battle for Britain' and our ability to 'stand alone,' and currently COVID-19 will be defeated, we are told, by the application of, 'good, British common sense.' In fact, as someone who has always regarded themselves as patriotic, I find the constant references back to the Second World War by politicians and certain sections of the media, to be very worrying. Victory in Europe was 75 years ago, but should we not be celebrating Peace in Europe for the last 75 years, and looking forward, rather than focussing on Spitfires over the White Cliffs?

English Education policy, in particular, has suffered from this same backward-looking approach. Starting with Secretary of State Michael Gove, and continuing with Schools Minister Nick Gibb, we have seen all secondary schools being told to focus on the traditional subjects of a 1950's grammar school curriculum, which, even then, was only deemed appropriate for a small percentage of the population. Acquisition of knowledge has become central, with application and skills pushed out to, or over, the periphery. We have seen the revision of examinations in order to make them harder, along with the downgrading of coursework, as though these alone will 'drive up standards.' In primary schools the focus on school inspections by the Office for Standards in Education (Ofsted), the impact of league tables and Standard Assessment Tasks (SATs) has distorted much of the curriculum.

To my mind, what we should be focussing on is a forward-looking patriotism which celebrates and builds on what we are good at now, not 75 years in the past. Collaboration, co-operation, creativity. We have all the benefits of living and working in a diverse, multicultural society. Working in partnership with our neighbours here, in Europe and across the world, brings enormous cultural, educational and economic advantages. And, to cut to the chase, we should be celebrating and building on the fact that we were the first country in the world to make Design and Technology a compulsory subject for all pupils from 5 to 16 when the National Curriculum was introduced in 1989. We were world-leaders then, but over the next 30 years not only have we allowed that lead to disappear, in some schools we have shamefully allowed the subject itself to be removed. We should be making the case for an education system fit for the mid-21st century, not one that seeks to replicate the early to mid-20th century.

Three and a half years into semi-retirement and away from direct involvement in Design and Technology (D&T), have enabled a degree of perspective on the subject that I have been involved with since the age of 11. This perspective has gradually developed over the course of these years, particularly as a result of my involvement in running some of the D&T Association's British Council-funded Continual Professional Development (CPD) teacher courses looking at global education and sustainability. But then over the last few weeks, since the COVID-19 pandemic has affected us, it has become more sharply focused.

At the time of writing COVID-19 has affected over 10 million people across the world and the global death toll is 500,000 and rising. Before the pandemic is over these numbers will increase significantly. However, the World Health Organisation[1] have been predicting for a number of years that between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhoea and heat stress. I'm not looking to downplay the devastating effect of COVID-19, but its mortality rate could end up being relatively insignificant compared to potential deaths from some of the other global challenges we face this century. One thing is for certain, if we are to overcome these massive challenges, we need creative solutions and creative designers, engineers, scientists and technologists to work on them.

The sustainability courses I referred to, and the teachers I have met on them, have convinced me of 2 things. Firstly, the continued enthusiasm, skill and commitment of D&T teachers and their ability to truly affect the life chances of young people; and, secondly, the critical importance and relevance of the subject for all pupils who will live and work in a society that is facing global challenges. COVID-19 is undoubtedly a global challenge, and one that is certainly different from the types of challenges we looked at on the courses. What it has done is transform the way the whole of society has had to operate and it is this that has made me reflect on what education, and D&T, might look like as we come out of lockdown with no vaccine available in the short term. What have we learned from the lockdown and what is teaching and learning going to look like in what is now being described as the 'New Normal'?

One of the main features of the lockdown has been a huge increase in online everything - shopping, healthcare, entertainment, communication and, of course, a massive experiment in remote teaching. The success or failure of this online teaching and learning should undoubtedly be the focus of thorough evaluation and research. Anecdotally it would appear that the outcomes have been mixed. Access has been variable and concern has been voiced over the inability of many disadvantaged pupils to benefit from these tools. Pupil engagement has also been mixed, with some pupils coping very successfully whilst others have struggled. With social distancing still being required during the exit from lockdown, class sizes will either need to be capped at around 15 or alternative 'bubble' arrangements implemented to allow a fuller return. The former would require doubling both the teaching workforce and the number of classrooms to allow some form of rota for in-school learning in the short to medium term. Therefore, it is the latter option which is likely to be favoured by the Government in England. It appears that they are already considering a range of measures for the restart which just happen to fit very well with their 1950s ideology: full class teaching; all students facing the front; a focus on a limited range of subjects, particularly maths and English, and with some subjects not being taught at all until summer 2021. However, if, or more likely, when the virus returns, irrespective of the approach adopted, there is every chance of further local or regional lockdowns over the coming year. This would tend to suggest the need for more effective and accessible online systems to support and supplement the potential reduction in face-to-face teaching.

Surprisingly, the Government has not led in these developments. In fact its only involvement was to put limited and belated funding into the establishment of an online 'academy' which was developed by well-intentioned teachers to meet demand in the early weeks of the lockdown. It would be scandalous if the Department for Education compounded their lack of leadership in this area by pouring further, significant public funding into this DIY-academy without putting a contract out to tender! Yet that is what the Government has signalled it intends to do and, as a consequence, it will very likely tighten its control on curriculum content and pedagogy. This needs to be urgently resisted and reconsidered. What is desperately needed is an approach that draws on the best research in online pedagogy allied to content development from subject experts (a role for subject associations) and produced by professional developers of online systems. The project brief should also include the requirement to develop online CPD modules for teachers. For too long teachers have struggled to be released to attend face-to-face CPD because of both teacher shortages and budget considerations. The need for online systems is only part of the CPD solution, but an important part and one that the Government should be prioritising and funding in order that a national, cost-effective system is available as soon as possible.

A second feature of the lockdown was the rapid abandonment of the 2020 examinations and SATs in favour of teacher assessment. If this could be done so easily with, I suspect, what will turn out to be so little negative impact on results, why can we not use this time to look again at the rationale behind our high-stakes examination system? How useful are the baseline tests in Reception? Should we be testing in Year 6 (11 year olds) when there is a body of opinion which suggests a baseline test in Year 7, when pupils change to secondary school, could be more useful? Do we actually need the examinations taken by 16 year olds in Y11 when all pupils are required to continue education to 18? Would this be the time to look at introducing the wider use of comparative judgements to make teacher assessments more reliable, easier and quicker? These are all opportunities to look ahead, to be proactive, to think and do things differently. But, where there are opportunities there are usually also threats. The early guidance on safe working in schools as the lockdown eases suggests classrooms devoid of resources which could become contaminated; classes of pupils sitting in distanced desks, facing the front and not being able to share materials, tools and equipment. It could easily turn into an even starker version of that 1950s education I referred to earlier.

And what of D&T in the New Normal? We start from a position of relative strength in that most secondary D&T environments were designed for groups of 15-20. But practical work relies on access to shared tools, materials and equipment. If this is going to be feasible Heads of Department should already be compiling their case for longer blocks of time (half days?), which would be educationally beneficial, more productive, as well as safer, with shared resources being cleaned only twice a day rather than after every 45 or 60 minute lesson. Consideration also needs to be given to the division of time between in-school and online learning. What aspects of the subject need face-to-face teaching and what can be successfully taught online? I don't think the answer is perhaps as obvious as it first appears as digital manufacture can be carried out remotely. Could this be the start of a more general move away from many of the traditional hand craft processes?

There are obviously lots of unknowns but as we emerge from the COVID-19 pandemic it is almost certain that the New Normal will be very different from the Old Normal. Already there are calls for wide ranging societal changes. For example, Green New Deal UK[2] have already started a 'Build Back Better' campaign which, "prioritises people, invests in the NHS and creates a robust, shockproof economy that is capable of tackling the climate crisis." However, opportunities are nearly always counter-balanced by threats, including concerns about the impact of increased reliance on technology, such as the loss of privacy and, as Naomi Klein[3] has written, "… we face real and hard choices between investing in humans and investing in technology. Because the brutal truth is that, as it stands, we are very unlikely to do both."

For education and D&T the biggest caveat has to be that any chance of major change will be significantly greater if Nick Gibb's vice-like grip on the Schools' Minister post is wrested from him - but let's think positively! One of the Government's pandemic mantras has been, "We follow the science," so we can but hope that the New Normal sees the return of education policy that is research-based and evidence-led; a move away from examinations to increased reliance on teacher assessment; a rebalancing of the curriculum with increased priority given to creative and technical subjects; a development of high quality, online learning to support in-school activity; and access for teachers to affordable and accessible online CPD - just to name a few. If only some of these come to fruition then the educational New Normal could be a huge step in a very positive direction.

[1] World Health Organisation; www.who.int/health-topics/climate-change#tab=tab_1

[2] Green New Deal UK; www.greennewdealuk.org

[3] Naomi Klein; The Guardian; 19.5.20; "How big tech plans to profit from the pandemic."

How focus creates engagement in Primary Design and Technology Education: The effect of well-defined tasks and joint presentations on a class of nine to twelve years old pupils

Annemarie Looijenga, Delft University of Technology, The Netherlands
Remke M. Klapwijk, Delft University of Technology, The Netherlands
Marc J. de Vries, Delft University of Technology, The Netherlands

Abstract

During a Design and Technology class, engagement is both required to start creative hands-on work and a sign of pupil's creative thinking. To find ways to achieve engagement, we can look to the Montessori tradition. Due to the fact that learning is regarded as feeding insight through experimenting, tasks have to offer pupils the opportunity to gain knowledge about isolated details of the learning situation. This is realised by brief, simple and objective tasks combined with liberty to approach the hands-on work in one's own way. Applied to Design and Technology, we can define brief, simple and objective tasks with a focus on a technique as an isolated detail of the learning situation. Offering liberty during hands-on work enables creative thinking. The deployment of well-defined tasks with a focus on a technique is possible by dividing a complex assignment into a collection of brief tasks with single problems and working towards single objectives in the topic, making use of a single technique. Such a collection is a format that has the potential to enable ongoing engagement. This case-study researches the actual effect of a stepwise organised collection of tasks on the design performance of pupils of nine to twelve years old. The results show that the tasks turned out to be useful in initiating engagement. In combination with joint presentations, ongoing engagement was achieved resulting in well-considered designs and products. In addition, dialogue with disengaged pupils delivered solutions towards engagement. As a side-effect of dialogue the teacher-pupil relationships and the pupil-pupil relationships improved.

Keywords

engagement, active Montessori approach, Design and Technology, creative hands-on work, stepwise approach, joint presentations.

Figure 1. Exposition of chairs

Introduction

Creative hands-on work, the creative handling of something with a technique as a means, is an essential element of the Design and Technology class. When pupils in class are disengaged, they not only signal absence of creative thinking, but they are also unready to instantly start creative hands-on work and they can distract other pupils in class.

An important part of creative hands-on work is discovery towards insight. Discovery only can arise when pupils are experimenting. To allow experimenting, liberty is necessary. Pupils have to be in charge of the determination of the focus of their attention to be enabled to accomplish the spontaneous activity that accompanies experimenting. The hampering of pupil's liberty, by forcing or nudging them to do something in a certain way, blocks the process of discovery. Not only liberty determines pupils' situational autonomy (Candy, 1987), but also the complexity of the learning environment. Overwhelming them stops the process of discovery (Dewey, 1910). Both the learning situation and the demands of the teacher can overwhelm them.

Montessori views a task as an experiment. In the Montessori tradition it is therefore common practice to apply the principle of liberty and the principle of avoiding overwhelming complexity. According to Montessori, liberty will lead to spontaneous activity. Therefore freedom of procedure during the performance of a task is required. The provocation of unnatural effort hampers liberty and blocks spontaneous activity (Gutek, 2004, p. 124). For the avoiding of overwhelming complexity pupils require brief, simple and objective tasks (Gutek, 2004, p.124). About her method, Montessori writes: "*(my) pedagogic experiments are designed to educate the senses*" (Fig. 2) "*(From earlier research with 'deficients' I know that) the education of the senses is entirely possible*." (in Gutek, 2004, p.153). "*(With normal children) it (the education of the senses) provokes auto-education*" (in Gutek, 2004, p.154). Auto-education is the opposite of training. Auto-education could be defined as self-constructing the own knowledge.

Figure 2. Montessori learning materials for learning to sort from large to small, thick to thin, high to low.

Design is another part of creative hands-on work. Design by its nature is adapting reality. For adapting reality is insight required. Insight can be acquired by experiment. Insight has to be understood as an accurate and deep understanding of reality. Insight can function in unknown situations as an anchor. The deep understanding of a situation can be applied to a comparable situation (Barsalou & Weimer-Hastings, 2005).

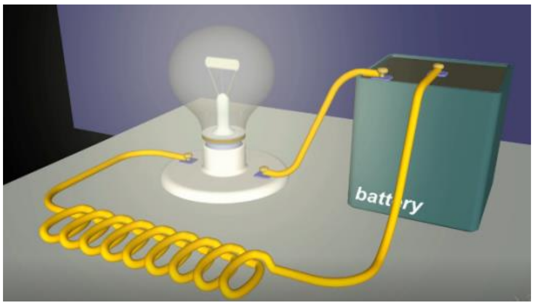

Figure 3. Electrical circuit. (The Editors of Encyclopedia Britannica. N.d.)

A simple example of a Design and Technology task that enables both aspects of creative hands-on work is the making of an electrical circuit (Fig. 3). When the pupils have a battery, a light bulb and wires, we can give the pupils the task to make the light go on (brief, simple and objective). The focus is on connecting the light bulb to the battery in a suitable way (technique). Experimenting is desirable. The pupils first have to discover the effect of the battery on the lamp. For that reason they have to design a circuit and try it out. Trial and error, tinkering with the wires, design and failure will lead to the discovery of a stable circuit and to growing insight. Ongoing experimenting will lead to an efficient stable circuit and to accurate and deep understanding of the phenomenon of conductivity of electricity.

Discoveries are required to guide insight. Thus one profit of the practice of creative hands-on work during a Design and Technology class is the generation of insight. Applying the idea of Montessori that her experiments are designed to educate the senses, for the Design and Technology class we can design experiments that educate the techniques. Thus another profit of the practice of creative hands-on work during a Design and Technology class can be the practice of the tasked technique.

According to the Montessori approach a well-defined Design and Technology task will be brief, simple, objective and designed to educate one technique. Dividing the mastery process of a complex Design and Technology topic into brief, simple and objective tasks, focusing on one technique, can be a way to achieve creative hands-on work towards mastery. Such a division naturally leads to a collection of tasks (Fig. 4). The tasks can differ from each other by variation in tasked technique, but also by variation in the requirements of an objective associated to the topic. The differentiation of tasked technique can result in a stepwise approach, but also into a collection of tasks around a theme. The differentiation of requirements of the objective will result in iteration of the performance of the task.

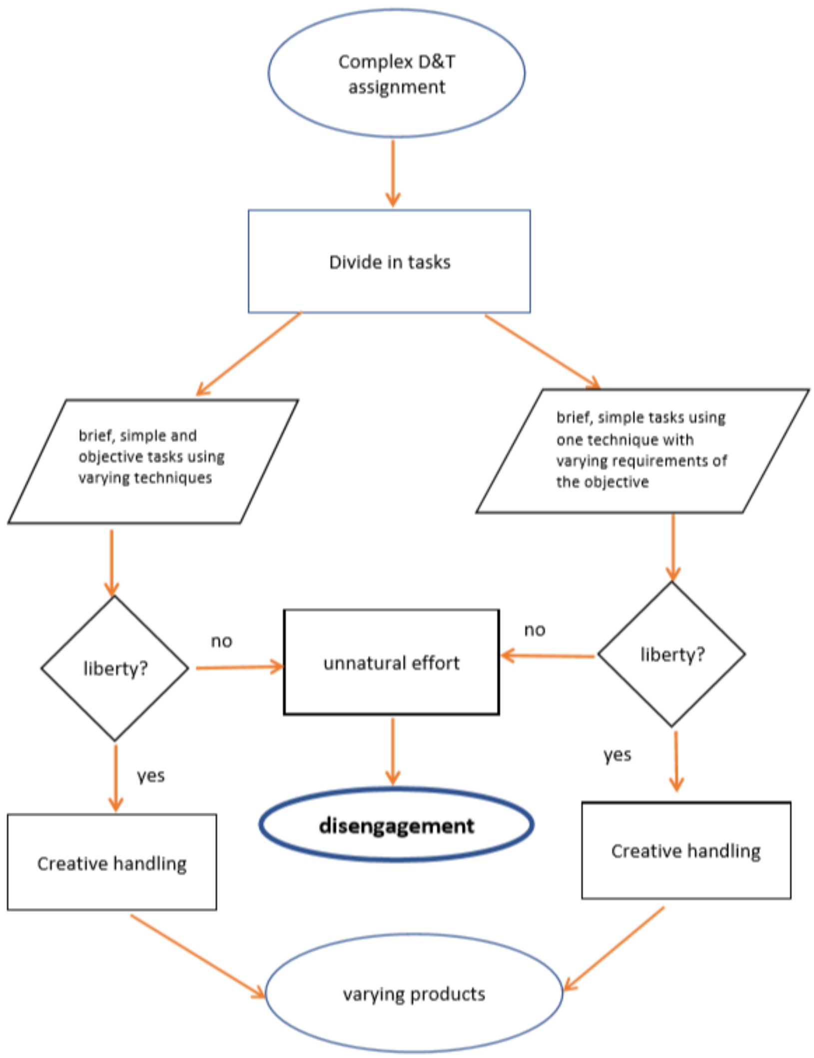

Figure 4. The transformation of a complex assignment in a collection of well-defined tasks

Formative reflection serves iteration, but also a stepwise approach. To get this done regular non-judgmental data collection is necessary. A joint presentation delivers an excellent opportunity for data collection, followed by reflection (Fig. 5). When the data collection is discussed on the basis of the question "What can we learn from this data?" followed by the question "What more do we want to know/accomplish?", increasing insight can arise for all participants. Such a joint presentation and discussion offer opportunities for active dialogue. Active dialogue transforms knowledge towards shared knowledge (Krauss & Chiu, 1998; Lemke, 2000; Mercer, 2013). Therefore, dialogue facilitates the increase of insight of all participants. On the base of shared insight, the participants together can determine the requirements of the next objective. Thus the formative reflection triggered by the questions "What can we learn from this data?" and "What more do we want to know/accomplish?" helps to set the next well-defined task.

As we have already researched a variant of this approach without variation in tasked technique, but with variation in requirements of the objective, with six to nine year olds, resulting in ongoing discovery and well-considered products (Looijenga, Klapwijk & de Vries, 2015), we wanted to know if a stepwise variant of the approach also should work. We also wanted to know if the approach should work for older pupils in a somewhat different stage of their knowledge and personality development than six to nine year olds are. Therefore we selected pupils of nine to twelve year olds. If the underlying assumptions are right, the well-defined tasks should also work for these older pupils.

The paper is organized as follows. In the second section we describe the theoretical framework. In the third section the research design of the case study is presented. Section four follow with results and in section five the conclusions. We end with a discussion and implications for education and further research.

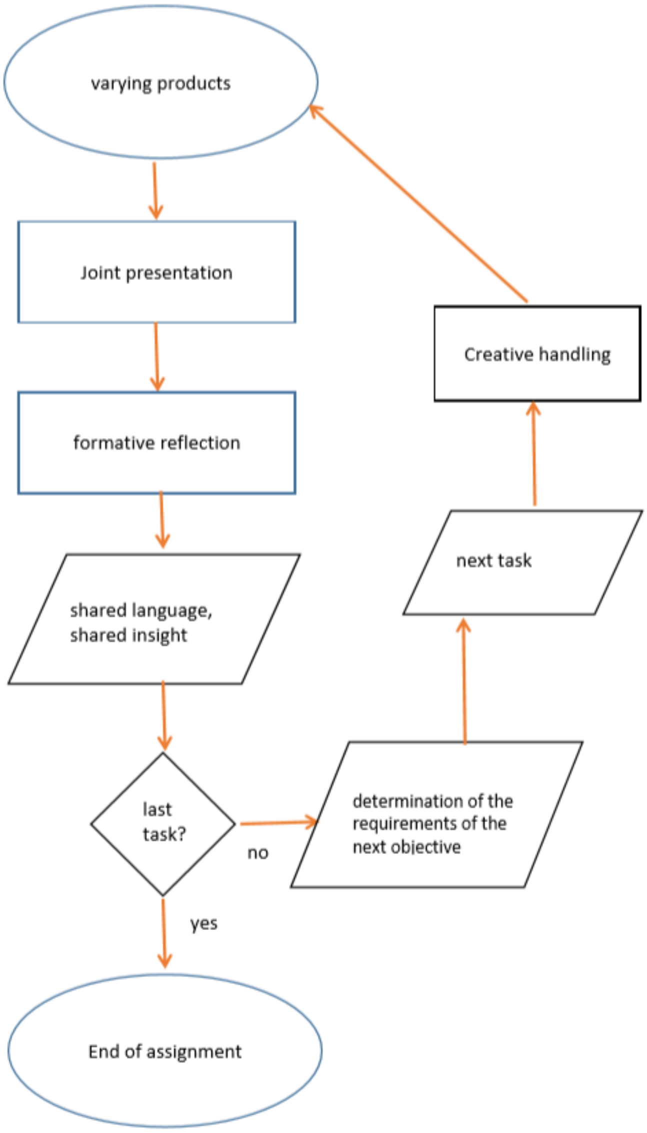

Figure 5. The functioning of joint presentations

Theoretical framework

Literature supports the importance and the feasibility of creating well-defined Design and Technology tasks. A teacher can create curiosity at the start of an activity by questioning pupils about an isolated detail of their everyday reality. Such an approach can start - even for young children - creative hands-on work (Chusilp & Jin, 2006). Presenting young pupils with design challenges that make use of their knowledge and skills can result in ongoing, iterative creative hands-on work (Strawhacker & Bers, 2014).

By starting with a focus on an isolated detail of their everyday reality, the elimination of curiosity - as a result of overwhelming information - is avoided (Dewey, 1910; Kirschner, Sweller, Clark, 2006; Wade & Kid, 2019). When the task also encompasses clear requirements of the objective, referred to by Hattie as success criteria (2012), situational autonomy arises (Candy, 1987). This situational autonomy is exactly the autonomy pupils need to start and continue creative hands-on work.

The effectiveness of the Montessori practice to divide a topic in brief, simple and objective tasks, is confirmed by Dolin, Black, Harlen and Tiberghien (2018). They view learning as making sense of new experiences. To make progress, learning has to be seen as making steps. Decisions about these steps are informed by evidence of what pupils already know and can do, in relation to short-term goals of activities of a particular lesson. Japanese Lesson Study also confirms the effectiveness of brief, simple and objective tasks (Doig & Groves, 2011). Goal setting and planning are the critical underpinning of a Japanese Lesson. According to Takahashi (2006), “a Japanese mathematics lesson is designed around solving a single problem to achieve a single objective in a topic” (p. 40). Additionally, Japanese mathematics lessons make use of joint presentations of all data, followed by formative reflection. The collection of the individual presentations results in a data set. Then, the data set is discussed on the basis of the question “What can we learn from this data?” followed by the question “What more do we want to know/accomplish?”.

> *In the structured problem-solving approach, Japanese teachers emphasise that one of the most important roles of the teacher during a lesson is to facilitate mathematical discussion after each student comes up with a solution. When the teacher presents a problem to students without giving a procedure, it is natural that several different approaches to the solution will come from the students. In order to do this, teachers need a clear plan for the discussion as a part of their lesson plans, which will anticipate the variety of solution methods that their students might bring to the discussion. These anticipated solution methods will include not only the most efficient methods but also ones caused by students’ misunderstandings. Thus, anticipating students’ solution methods is a major part of lesson planning for Japanese teachers. Towards the end of a lesson, a teacher often lead the lesson to pull all the different approaches and ideas together to see the connection. Then, he or she summarises the lesson to help students achieve the objective of the lesson. The teacher often asks students to reflect on what they have learned during the lesson.* (Takahashi (2006, p.42)

Joint presentation by means of active dialogue are in line with an aspect of the Montessori approach, figured out by Maria Montessori after the Second World War. She added active dialogue to her approach with the objective to provide children with experimental insight towards peace (Montessori, 1972). The active teacher acts as a representative of society and provides the pupils with opportunities to discuss and transform their opinions towards insight in responsible well-thought out opinions. This approach is highly topical, because current social challenges such as racism, discrimination and so forth, call for responsible well-thought out opinions. In this active approach the teacher not only creates a learning environment and defines tasks, but also participates in class through dialogue with the pupils. Such teachers not only prepare themselves inwardly, but are also open for the essence of dialogue; knowledge transformation towards insight (Christensen, 2019).

The idea of joint presentations is clearly elaborated in a book about the significance of Hannah Arendt at work. The essays on professionalism in education, care and well-fare highlight the important role of having different point of views around the table. Hannah Arendt calls this way of discussing 'the Greek Solution' (Berding, J. 2017; Arendt, 1958/1998). Around the table all participants can 'en plein public' explore a question. This exploration ideally results in a sharing of experiences and perspectives on the topic, whereby truth, in the form of solutions and answers are of less importance. An important characteristic of this joint presentation of thoughts and ideas is therefore the absence of moralising. Such a joint presentation leads to critical self-reflective thinking and understanding. For Arendt, as for Aristotle, education is the means whereby pupils achieve personal autonomy through exercising independent judgement and attain adulthood through the recognition of others as equal but different. The teacher takes, during education, the role of a representative of society (Nixon, 2020, pp. viii).

> *The teacher's qualification consists in knowing the world and being able to instruct others about it, but his authority rests on his assumption of responsibility for that world. Vis-à-vis the child, it is as though he is a representative of all adult inhabitants, pointing out the details and saying the child: This is our world.* (Arendt & Kohn, 2006, pp. 186).

We can find the same idea of joint presentation in the appendix to the Dutch lesson "geblinddoekte race" (blindfolded race) in the "Buitenlesbundel-2018" (Outside lessons collection 2018) (Jantje Beton & IVN, 2018) from the project "The power of play". This project is a collaboration of the Dutch organization "Jantje Beton" and the international organization "Right to play". The appendix describes the RCA method, that is used at schools in Rwanda. RCA stands for Reflect, Connect, Apply. This methodology puts the child at the centre of their learning. After participating in an activity, children are led through a series of questions, encouraging them to consciously reflect on the activity, connect the gained knowledge to earlier gained knowledge and then think about future applications.

Research design

The case study reported in this article has a history. A few months before the case-study even was considered, the researcher, a trained Montessori teacher, did a pilot study on a different location of the Montessori school, where the final case-study should take place. The idea was to find out more about the relationship between the format of activities in class and the engagement of pupils in class. For that reason the researcher cooperated with the Arts and Crafts teacher at that location, who taught several classes of six to nine year old primary pupils. The cooperation resulted for the pupils in increased engagement and, for the researcher and the teacher, in enlarged insight on the effects of the format of a task on the engagement of the pupils. The researcher learned from the teacher that focusing a task on a technique enabled the pupils to design freely. The teacher learned from the researcher that a single problem combined with a single objective created the required situational autonomy to enable pupils to start designing.

In response to the success of the pilot study the school board requested a case study of the nine to twelve year olds on another location. The Arts and Crafts teacher on that location agreed to participate in study. The school board granted permission for the publication about the case study and for the associated off-line video recordings. In preparation for the case-study an orientation period took place, in which the researcher assisted the Arts and Crafts teacher concerned in order to get acquainted with her approach and the situation during her Arts and Crafts classes. During the orientation period the researcher noticed the existence of confusion and disengagement in class, probably partly due to missing shared routines and language (the Arts and Crafts lessons had only just started at this location). The researcher concluded that this particular situation would offer an excellent chance to research if the stepwise variant of the approach with well-defined tasks and joint presentations should work. In addition, it could be researched if this approach also should work for older pupils of nine to twelve year olds. If the underlying on active Montessori approach based assumptions are right, the well-defined tasks combined with joint presentations should have a positive influence on creative hands-on work, showing in engagement of the pupils.

The goal of the case study was to identify the effect of an intervention in which the teacher – with assistance of the researcher – introduces a design assignment in the form of a series of well-defined tasks combined with joint presentations at the end of each lesson. The central research question was:

- What is the effect of dividing a complex Design and Technology assignment into well-defined tasks, combined with joint presentations?

The sub questions were:

- What is the effect on the design performance of pupils aged nine to twelve years old?
- What is the effect on collaboration in class?
- What is the effect on the teacher?

If the approach turns out to have a positive effect, we can continue with quantitative research in order to find out more details about the effect of well-defined tasks in the Design and Technology class.

Participants and intervention
The preparation and implementation of the lessons, by means of dividing an entire assignment in ten brief, simple and objective tasks, each centred around a specific technique, was done by the Arts and Crafts teacher assisted by the researcher (the first author of this article).

The STEAM assignment “Make a mini chair" (Fig. 1) (Petiet, 2009) was chosen, because it suited the dividing in tasks. It also suited the specific experience of the teacher, because the Arts and Crafts teacher was an experienced furniture designer, who did an additional study to become a qualified Arts and Crafts teacher. Each task was brief, simple and had an unambiguous goal, defined by clear and concrete objectives (Table 1). The objectives linked the tasks to the use of specific techniques. The subject 'chair' was chosen, because a chair is a familiar object. At the same time a chair can take many different forms and offers pupils freedom to design and model the object in an individual way.

Table 1. Task order in case study "Make a mini-chair:

Nr	task	objective
1	design a chair on a piece of paper	Sketch a 2D chair, that can be transformed to 3D parts
2	draw the components of the chair on paper	The components fit in a 3D construction of cardboard
3	cut out the components with scissors	The components are replicable in cardboard
4	assemble the components with glue	The assembled paper chair fits together
5	if necessary; re-design	Replication to cardboard parts towards a firm and comfortable chair is possible
6	draw the components on cardboard	The paper components are replicated on the cardboard in a fitting way
7	cut out the components with a knife	Handle the knife in an appropriate way
8	assemble the components with glue	The cardboard parts fit together
9	if necessary; solve construction problems	The chair is firm and comfortable
10	paint and finish your chair	The chair is good looking

The same lesson took place three times a day to groups of eight to thirteen pupils, all aged nine to twelve years old, in total forty-nine pupils. Each group received four different lessons. The composition of the groups was done by the two class supervisors. Each group comprised of pupils from both school classes.

Data collection and analysis

The type of research was action research, because of the (corresponding to the active Montessori approach) required active role of the researcher and the teacher. Data was collected in real time by the researcher through observation and questioning of the pupils. After the lesson additional data was collected by the researcher through discussing the events with the teacher. During the first three sessions the researcher observed and noted in a log the course of the class with special attention for pupils' engagement as an observable expression of creative thinking. The researcher shared her observations on the fly and after class with the teacher and noted the discussed observations and the teacher's reactions also in the log.

During the verbal sharing of observations the researcher highlighted the relationship between the course of the class and the accompanying appearance of engagement as an expression of creative thinking. All sessions were video recorded from a fixed place, with the objective to have an extra, impartial eye to review the sessions. At the fourth, last day of the sessions the researcher was absent, but the teacher reported the events to her, by phone, after the lessons.

Results

The proceedings during the four sessions for the three groups are described below.

The first session

The teacher started the lesson with a PowerPoint introduction about the function of a chair and the purpose of the assignment. Then, in short, she presented all ten tasks to each group of pupils. Next all pupils started the first task, 'designing a chair on a piece of paper'. When finished, they could start the second task, 'drawing the components of the chair on paper'. After this, they were allowed to continue with the third task, 'cut out the components with scissors' and subsequent task 4, 'assemble the components with glue' (Fig. 6). Dependent on pupils' contentment with their paper model, they could 're-design' (task 5) or start to 'draw the components on cardboard' (task 6). At the end of the first session the pupils were working on various tasks of the assignment. Where a single pupil was already getting around with task 7, 'cutting the cardboard components', one third of the pupils were still in the 'draw components on paper' task 2. A few pupils did not get past task 1 'design a chair on paper'.

Figure 6. Working with paper

During the first part of the first session many pupils had trouble to start the sketching of a chair in an experimental way. When asked, they answered that they thought they had to produce a nice chair in one attempt. The teacher and the researcher were busy with explaining to the pupils that the task was meant as an experiment towards the objective, using sketching as a means to get a feasible design.

An example of this situation is a dialogue between the researcher and three pupils. The researcher showed some samples made by other pupils and guided these pupils' attention to the details that make chairs solid and comfortable to sit in. This guidance did not result in them working. Therefore the researcher suggested that they leave class and come back another time, because the pupils apparently were not intending to start working as there was only 10 minutes working time left. Starting a new task would not be very meaningful. Responding to the suggestion of the researcher, Pupil 1 asked “Can I transfer my sketch to the cardboard now?”. The researcher answered: “No, you first have to make a proper paper sketch of a chair, that meets the objective of solidity and comfortable sitting. When you have managed to make such a sketch, you can start making a cardboard copy.” Pupil 1 responded; “It is already proper”. The researcher responded: “I cannot see anything that is proper; your sample can only lay down.” Pupil 1: “You should make one that stands up.” In response, the researcher showed him the cardboard copy of the chair she constructed as an example to show during the lesson. The pupil responded with: “Of course that one stands up; it is made of cardboard!” The researcher explained that she started with a paper exemplar and that she met many problems. She solved all these problems, one at the time, until the chair was solid when standing up. Subsequently she guided the three pupils’ attention (Pupil 2 and Pupil 3 were attentively listening) towards the specific dimensions of the parts of the chair and the differences between the dimensions of the parts of the original chair and the chair that Pupil 1 had designed. After that she guided attention to the different specific angles between the parts of both chairs.

After this instruction, Pupil 1 told the researcher that he was willing to make a table. Pupil 2 agreed with him. Pupil 3 hesitantly started task 2, ‘draw the components of the chair on paper’. The researcher did not agree with the proposal to make a table instead of a chair. She made the pupil choose between an immediate redesign of his chair in class or taking time by thinking it over and bringing in a redesigned chair during next class. Pupil 1 remained distracted. In response to his distraction the researcher advised him to take some rest outside class and continue the task later on. Pupil 1 left the classroom. Then Pupil 2 started task 2 ‘draw the components of the chair on paper’, and finished task 3 ‘cut out the components with scissors’ and task 4 ‘assemble the components with glue’ very quickly (five minutes!) resulting in an original, solid chair. He even managed to finish task 6 ‘draw the components on cardboard’. The same applied for Pupil 3; he also delivered a solid chair at the end of the session.

In general, at the end of the first session the intention was to share all processes of transforming the 2D model into 3D parts. However, the lesson was over before there were enough produced to share. Therefore the teacher and the researcher decided to omit the moment of sharing in all three groups.

The second session

At the start of the second session a smaller number of pupils had difficulties in starting the task. The researcher discussed the reasons of their passiveness (one at a time) with pupils who had not started. After having looked backwards, the researcher asked these passive pupils to propose a solution that would not disturb their class mates. Then, the researcher and the passive pupils discussed the proposed solutions. After this discussion most former passive pupils were enabled to hesitantly start working. It was noteworthy that the subsequent hands-on work of these pupils sometimes showed awkwardness. The scaffold of these pupils resulted in the disappearance of hesitance. Some other pupils started with looking at peers to see how they continued the assignment. Then they started working.

An example of the effect on passive pupils of looking at peers, is the spontaneous presentation of a pupil, who had already finished the assembly of paper components with glue (task 4), to three new starting pupils. This pupil told the others about his design and creation-process.

While he continued working, the new starting pupils watched his working and asked him questions. The task he was working on, was the transfer of the paper components to the cardboard (task 6) and later the cutting with the knife (task 7). The freshly started pupils watched the process of transfer from paper components to cardboard components and realised that not every 2D thought out chair would be suitable to be made of cardboard components. The effect of this realisation was that they redesigned their original design sketches.

From the moment that the teacher and the researcher experienced the effect of looking backwards, through asking for reasons of passiveness and on looking forwards through asking for their own solutions, the teacher and the researcher realised that this method not only was suitable for passive pupils, but also the other way around for stagnating pupils. They started to deploy the method of looking forwards and then backwards to support pupils' thought processes.

An example of looking forwards and then looking backwards during task 2 was first focusing on the objective of task 9 "The chair is firm and comfortable" and then focusing on the objective of task 1 "Sketch a 2D chair, that can be transformed to 3D parts". This was done by talking about a pupil's design in terms of "Is it easy to make?", "Will it be firm?", "How do you sit on it?". Then the pupil was questioned about the cause of to be expected failures. Looking forward helped the pupils to anticipate conditions and looking backwards helped the pupils to discover flaws in earlier stages of the assignment, leading to an eventual redesign of the chair. From this moment on the pupils also applied this support in their collaborations.

During the second session most pupils managed to start cutting out the components with a knife (task 3). At the end of the session in all groups all pupils had finished tasks 1, 2 and 3. Some pupils already managed to assemble the cardboard components with glue (task 8).

A short sharing of results and applied procedures ended this session. The focus of attention of the teacher and the researcher during the main part of this session was on the transformation from 2D to 3D and on the correct use of a knife.

The third session

During the third session all pupils were working on cutting and assembling. One pupil told the teacher that he would rather have skipped the lesson. Responding to his remark the researcher sat next to the pupil and asked him about the reason for his feelings about the lesson. She began with saying: "Your obvious aversion does not feel good for me. Are you aware of the unpleasant effect?". Then: "Is the task clear to you?", "Do you think the task is feasible?", "Have you already thought out a nice design?". Meanwhile she assisted him in the cutting job. Although the pupil did not say much, he relaxed and started concentrated working. After 5 minutes he was enabled to work without assistance.

Most pupils were showing a lot of joy during working. The pupils regularly came up with creative ideas like a 'wobble' chair (Fig. 7).

Figure 7. Wobble chair "Wiebeline"

Another pupil did a remarkable lot of measuring and redesign to make her chair solid. During solving construction problems (task 4 and 8), some pupils got ideas for fixing stability problems.

Figure 8. The use of paper strips to fix connections

For instance, paper strips were creatively used to fix absent cardboard connections (Fig. 8). Other pupils had simple ideas for a new design and started the process of making a chair all over. Half the pupils finished their chair completely. A significant number of pupils could already colour and finish the chair (Fig. 1). At the end of the session, during joint presentation, every pupil showed his/her work and reported shortly about their creation and plans for the next session.

The fourth session

During the fourth session, most pupils finished their chair and proceeded with a self-chosen job. Some pupils had to finish their chair in a fifth session or in class. The teacher told the researcher on the phone that the class-atmosphere was really good; pupils showed pleasure in working. The teacher also told the researcher that where she felt stressed and insecure during the first sessions, she was feeling calm and decisive during the third and fourth sessions.
At the end of the session, during a joint presentation, every pupil showed his/her work and reported shortly about the creation. The teacher made a small exhibition in the central hall (Fig. 1).

Conclusions

To answer the question: *"What is the effect of dividing a complex Design and Technology assignment into well-defined tasks, combined with joint presentations?"* we can conclude that in this case study the well-defined tasks resulted in growing insight in the possibilities and impossibilities of the used techniques with regard to the design challenge, showing in well-considered designs and products. From the moment that the joint presentations were deployed, a significant increase of collaboration, accompanied by an intensification of discovery, appeared. The offered liberty caused varied ways of creative application of the tasked technique resulting in varied design ideas. Figure 1 shows examples of the variety of ideas.

To answer the sub question: *"What is the effect on the design performance of pupils aged nine to twelve years old?"* we can conclude that the quality of the design performance of these nine to twelve years old pupils improved by the focus on techniques and the offered liberty. Not only the quality of the designs improved, but also the intensification of the performance. The quality showed in well-considered designs and products and the intensification showed in an increase of engagement, interest and collaboration.

To answer the sub question: *"What is the effect on collaboration in class?"* we can note that from the moment that the joint presentations were deployed, collaboration was evolving. During the joint presentations every pupil showed his/her work and reported shortly about the creation. Because the tasks were the same for all pupils in the class, the design processes and design products were comparable. As a result the joint presentations were enriching each pupil's individual knowledge. The rise of shared language about shared knowledge fed the increase of collaboration.

An example of evolving collaboration was the growing attention of pupils for their peers. An example was the pupil who showed attention for the needs of three newly starting pupils by talking about his design and creation-process during working. While doing so, the fresh starting pupils watched his working and asked him questions, to which he patiently replied. This initiated their awareness about the fact that not every 2D thought out chair could be made of cardboard components. The awareness was followed by redesign. Another example occurred during the third session in the second group. One pupil showed other pupils how to handle the knife.

To answer the sub question: *"What is the effect on the teacher?"* we can conclude that the increasing engagement of the pupils created increasing room for focus on pupils' execution of the techniques, resulting in active support of hesitant pupils. For instance, during the second session the increased room for assistance enabled the teacher to assist the pupils in the transformation of the designed chair into chair parts (task 2) and the correct use of the knife (task 7).

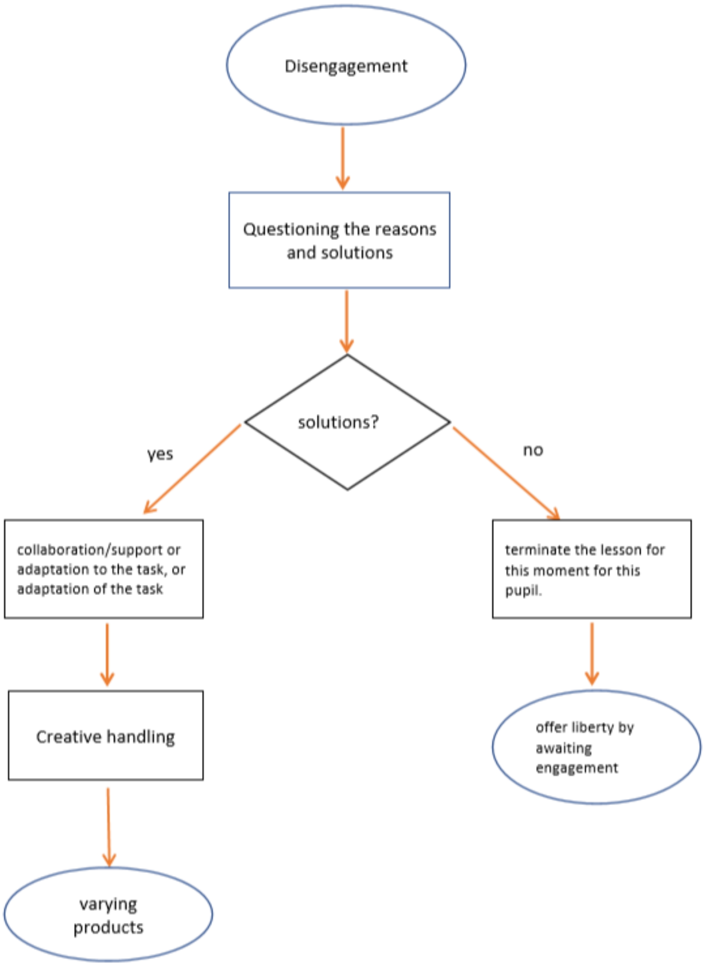

Figure 9. The functioning of liberty

Furthermore, the application of the Montessori view on the importance of the liberty of the pupils, helped the teacher and the researcher to accept the disengagement of pupils. Instead of investing energy and time in forcing or nudging to stop the disengagement, this acceptance helped the teacher and the researcher to question the disengaged pupils about the causes of their disengagement (Fig. 9). This acceptance and questioning worked out well. The waiving of a demand for unnatural efforts prevented resistance. The absence of resistance left the teacher and the researcher even more time for the active support of pupils.

Discussion and implications

Class atmosphere

One major observation during this case study was that especially the atmosphere in class easily improved. At the start dominated disorientation and passiveness the class-atmosphere, but during the third session the pupils were showing focus and enjoyment. During this session the pupils were finishing the thought-out chairs by themselves. This is an outcome of great significance, because improvement of class atmosphere is a well-known subject in the general pedagogic and educational literature. These sources often mention the strategy to improve class atmosphere through the development of positive teacher-pupil relationships. According to

Wentzel (1998) positive teacher–pupil relationships correlate to motivation and school success and are therefore important for pupils. Positive teacher–pupil relationships are according to other authors also important for teachers, because they allow teachers to experience more job satisfaction (Veldman, van Tartwijk, Brekelmans & Wubbels, 2013), teacher wellbeing (Gu & Day, 2007), and lower levels of stress (Yoon, 2002).

Where these literature sources focused on the creation of positive teacher-pupil relationships, we focused on the definition of brief, simple and objective tasks and we combined the tasks with joint presentations. We started with the creation of well-defined tasks. Secondly, during the lessons, we tried not to hamper the liberty of the pupils in any way whatsoever. Thirdly, we used joint presentations towards increasing collaboration.

As a result, we found in this study a gradually lowering level of stress in the pupils accompanied by an improving level of engagement of all pupils in the class. In addition the researcher observed a gradually lowering level of stress in the teacher and an improving level of decisiveness. Both facts benefitted the teacher-pupil relationships.

Therefore, we can say that we found a different way of achieving a positive class atmosphere. We think that the employment of well-defined tasks, combined with respecting pupil's liberty will provide opportunities to start dialogue between teachers and pupils. The joint presentations will feed collaboration. Both occurrences will contribute to positive relationships, showing in a positive class atmosphere.

Further research

The use of well-defined tasks will lead most pupils to creative hands-on work. In this study some cases of passiveness showed up. Additional measures, such as the questioning of reasons for their disengagement, and asking pupils to invent solutions for their disengagement, appeared to be necessary. Further research is useful to understand the effect of additional measures on creative hands-on work during a Design and Technology class, and how they can be best combined.

Our observations during the case-study indicate that well-designed tasks combined with offering liberty suit creative hands-on work during the Design and Technology class. Combined with the use of joint presentations the well-defined tasks appeared to lead to a multiplication of ideas, and to developing collaboration. These observations implicate that the well-defined tasks in combination with joint presentations are probably also applicable in creative classes in other domains. Further research is necessary to investigate this idea.

Another interesting item for further research could be reproducibility. The described effects on the pupils in a Design and Technology class are found in a Montessori school. In the Montessori tradition it is customary to enable pupils to start their learning through hands-on work, with a focus on a separated feature of the used learning material. (fig. 3). After this start, application of the gained knowledge on other aspects of reality has become possible. Thus, first the hands and then the mind becomes active, resulting in the achievement of grounded knowledge (Barsalou & Weimer-Hastings, 2005). It would be interesting to research the effects of the same intervention on pupils in a Design and Technology class in schools that pursue a more traditional educational approach. What will be the similarities and what will be the differences between the findings in our case-study and these schools?

The case-study reported in this article deals with one researcher and one teacher. Other researchers and other teachers could investigate the applicability of the approach and fine-tune the factors of the task definition and the joint presentation.

Transfer of the findings to other teachers

A suggestion, that arose from experiencing the successful collaboration with the Arts and Crafts teacher, is that it is worth trying coaching in class using well-defined tasks and joint presentations. This help can come from an expert coach or an expert colleague teacher. In class, both the coach and the person being coached will meet the same problems, but may have different interpretations of liberty and inability. This facilitates dialogue. Teachers can, for instance, through this coaching start to see new possibilities to handle a pupil's disengagement. By drawing attention to clear occurrences of disengagement, coaching can help teachers to transform restraining assumptions. For example, the teacher in this case-study observed the effect of accepting the disengagement of pupils. Through this observation the teacher became enabled to transform her assumption that pupils require forcing or nudging in order to start them working. Instead she was enabled to question disengaged pupils about the reasons of their disengagement. She also asked the pupils to invent solutions. These interventions led to engagement (Fig. 9).

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25.2

The development of pedagogical infrastructures in three cycles of maker-centered learning projects

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Abstract
The purpose of the present investigation was to analyze the pedagogical infrastructures in three cycles of seventh graders' co-invention projects that involved using traditional and digital fabrication technologies for inventing and creating complex artefacts. The aim of the projects was to create high-end multi-material makerspaces by expanding Finnish craft classrooms with instruments of digital fabrication, such as micro-processors, wearable computing (e-textiles), and 3D design and making, for enabling creation of student-designed multi-faceted inventions. Through a qualitative meta-analysis of the three successive learning-by-making projects, we explored the kinds of pedagogical infrastructures required for fostering knowledge-creating practices of learning. Pedagogic infrastructures refer to the designed arrangements and underlying conditions of implementing an extensive study project in classroom practices needed for reaching the learning objectives. We analyzed the epistemological, scaffolding, social, and material-technological dimensions of the enacted pedagogic infrastructures. In accordance with design-based educational investigations, we collected a variety of data (classroom video recordings, teacher and tutor interviews, invention challenges, learning assignments, and working schedules) across three year-long developmental cycles. We discuss the limitations and opportunities of maker-centered learning settings as well as considerations for future development of makerspace as pedagogical innovations for integrating socio-digital and material-technical practices and spaces for learning.

Keywords
Design-based research, digital fabrication, knowledge-creating learning, maker-centered learning, pedagogical infrastructures, socio-digital practices, socio-digital technologies

Introduction
Various educational researchers (Clapp, Ross, Ryan & Tishman, 2016; Honey & Kanter, 2013) have emphasized that elements of maker culture should be rooted in schools to make school learning a more inspiring experience for increasingly socio-digitally engaged young people. Maker-centered learning practices provide ample opportunities for bridging digital divides, overcoming creative participation gaps, and reconnecting informal and formal learning activities (Jenkins, Clinton, Purushotma, Robison, Weigel, 2006; Ito, et. al.,2013). Preparing young people for increasingly innovation-driven professional lives and rapidly transforming knowledge societies, laden with global and local risks and challenges, necessitates putting effort into building innovation capabilities from the beginning of education. Learning by making engages teams of students in working with invention challenges by designing and creating

tangible artefacts with digital and traditional technologies. Makerspaces provide multi-faceted technological (tools) and social (community) resources that enable people to participate in creative practices of inventing and making artefacts (Halverson & Sheridan, 2014). Such practices are often strongly inter-connected with science, technology, engineering, arts, and mathematics (STEAM) learning (Blikstein, 2013; Hatch, 2014; Petrich, Wilkinson & Bevan, 2013). Although many researchers are excited about the educational potential of socio-digital technologies and makerspaces, maker-centered learning, however, often takes place only in afterschool programs with museums, libraries, or DIY and other organizations rather than in schools (Gutwill, Hido & Sindoft, 2015; Halverson & Sheridan, 2014; Kafai & Peppler, 2011). Only a few researchers have examined how learning by making can be integrated with school pedagogical practices for systematically educating personal and collaborative creativity in formal education.

Implementing maker-centered education at schools is challenging because it requires both sophisticated socio-digital teacher competence and cultivation of novel pedagogical practices. Pursuit of maker-centered learning appears to call for non-linear pedagogy that involves teams of students creating unforeseen creative solutions for ill-defined, authentic, and complex challenges (Seitamaa-Hakkarainen, Viilo & Hakkarainen, 2010). Learning to productively deal with uncertainty in the creative process is necessary but may also be challenging for teachers, who must be able to fluently adapt to emergent ideas, unfamiliar technologies, unforeseen epistemic needs, and unpredictable events and actions. There are not many studies regarding adequate collaborative roles of teachers and other facilitators when orchestrating longitudinal maker-centered learning projects. Consequently, there is an urgent need for promoting teachers' professional-collaborative development as well as finding new systematic ways for fostering young students' collaborative learning in technology-enhanced makerspaces.

For synthesizing our experiences of struggling with challenges, we conducted a qualitative meta-analysis of the three maker-centered learning projects by relying on the pedagogical infrastructures framework (Lakkala, Muukkonen, Paavola & Hakkarainen, 2008). Pedagogic infrastructures refer to the designed arrangements and underlying conditions of implementing an extensive technology-mediated learning project needed for reaching the learning objectives in classroom practices. Our investigation aims to examine the essential underlying pedagogical conditions that have to be designed, implemented, and addressed in order to foster students' targeted collaborative making practices at school. We conducted a series of three educational design-based research cycles, which engaged Finnish lower secondary (Grade 7th) students, under the guidance of teachers and researchers, in maker-centered learning for creating co-innovations and building knowledge embedded in artefacts. We describe how the learning-by-making projects evolved through the cycles and how these projects were gradually implemented in regular infrastructures of schooling. Below, we first describe the pedagogical underpinnings that have informed our work. We then present the pedagogical infrastructures framework (Lakkala et al., 2008). Subsequently, we utilize this framework in the qualitative meta-analysis of the three projects, focusing on their contexts, the associated learning activities and teacher teamwork, as well as the tools and materials provided to the students. Finally, we discuss the implications of this study for maker education.

Characteristics of Maker-Centered learning and teaching

Learning through collaborative making is based on a theory of constructionism (Papert, 1980) that regards learners as builders of their own knowledge and views learning in terms of creating artefacts and inventions and cultivating associated novel ways of thinking and acting (Kafai, 2006). To that end, makerspaces provide a wide variety of traditional and digital fabrication tools, materials, and resources for supporting knowledge-creating learning (Paavola & Hakkarainen, 2014). Makerspaces can be seen as dynamic, loft-like spaces where children come with their parents or teachers to pursue their interest-driven making projects, share their design challenges, and work individually or collaboratively—often supported by adult facilitators (Gutwill et al., 2015). Rather than merely working with ideas or building knowledge, participants are challenged to apply their knowledge and understanding for inventing, designing, and making materially embodied artefacts. Maker-centered learning involves students in externalizing their ideas through conceptual (spoken or written ideas), visual (drawings, sketches), or material (3D prototypes and models) artefacts, creating an opportunity for themselves and their peers to build on these ideas, discuss and elaborate upon them, and embody ideas in more advanced artefacts.

Such makerspace philosophy underlines democratization of knowledge and power, open-ended knowledge-creating projects, creativity and design thinking, systematic innovation education, and support from peers, communities, and experts (Sheridan et al., 2014). Maker-centered learning aims to develop “a creative maker mindset” (Dougherty, 2013) in which students develop their creative capabilities and form habits of engaging in the possibility thinking involved in pursuing epistemic objects. Makerspaces are also designed to provide support for personal and social identity development (Fasso & Knight, 2019). The educational importance of participating in these kinds of embodied activities and working with concrete artefacts has been emphasized by many researchers (e.g. Blikstein, 2013; Kafai, Fields & Searle, 2014; Kangas, Seitamaa-Hakkarainen & Hakkarainen, 2013). Maker-centered learning resembles closely modern Design & Technology education (D&T); however, the bases of these two are different. In many countries, D&T education has an established role in the formal educational system and the contents and aims are defined in the curriculum. On the contrary, maker-centered learning originates from informal and non-formal learning environments, such as museums and libraries, where peer supported and networked learning are strongly emphasized. Moreover, maker-centered learning, from its very premise, is transdisciplinary in nature, which is not always the case in formal schooling.

Furthermore, makerspace activities resemble design-studio practices. Sawyer (2018) proposed that design-studio pedagogy represents a historically developed cultural model of teaching and learning creative practices in the craft and design disciplines. In maker-centered learning, the organization of pedagogical settings; the nature of tasks, tools, and methods employed; and social organization should enable the development of students’ collaborative invention skills and understanding of design and making processes. In accordance with authentic contexts, students should be introduced to the process of working with open-ended but focused projects, meeting external constraints determined by an invention challenge (Sawyer, 2018). These tasks should prompt students to experience the complexity of the entire design and making process: defining the constraints, exploring and sketching invention ideas, and experimenting with various materials.

Artefact-mediated learning by making is a nonlinear process where neither can the concrete goals, stages of activity, tools and methods, or resulting products be pre-determined nor can the flow of creative activity be scripted (Sawyer, 2018; Scardamalia & Bereiter, 2014). Investigators of technology-mediated learning have widely adopted such approaches on nonlinear pedagogy, such as Learning by Design™ (Kolodner et al., 2003), project-based learning (Greeno, 2006), and knowledge building (Scardamalia & Bereiter, 2006). In our previous research on maker-centered learning, we created the Learning by Collaborative Design (LCD) (Seitamaa-Hakkarainen et al., 2010; Kangas, & Seitamaa-Hakkarainen, 2018) approach. It is a pedagogical framework for modelling nonlinear design and knowledge-creation processes in educational settings. Designing and making are characterized by emergent "epistemic objects" (Knorr Cetina, 2001; Paavola & Hakkarainen, 2014), that are formed and modified by students during the course of pursuing them. The envisioned epistemic objects guide and direct the process, as they are constantly being further defined and instantiated in a series of successively more refined visualizations, prototypes and design artefacts. In maker projects, the students need to handle various epistemic issues, ranging from making a tangible material object to tackling theoretical scientific concepts. Their epistemic agency is materially entangled, as the material objects involved in the process affect the intertwined generation of design ideas and problems (Mehto, Riikonen, Hakkarainen, Kangas, & Seitamaa-Hakkarainen, 2020). The non-linear pedagogical approaches underline iterative, cyclical processes and the importance of engaging students in sustained efforts to solve meaningful design and making challenges.

Pedagogical infrastructures in the context of Maker-Centered learning

Makerspaces are usually seen as distinct from structured, formal learning environments, such as schools (e.g., Hatch, 2014; Halverson & Sheridan, 2014). Makerspaces emphasize personally significant informal learning and encourage purposeful tinkering and peer-supported inquiry, whereas maker-centered learning in schools tends to be more pre-planned, structured, and guided by teachers (Halverson & Sheridan, 2014; Sheridan et al., 2014; Martinez & Stager, 2013. Facilitation is an important component of the makerspace and involves maintaining the balance between offering enough support while keeping a sufficient distance with self-directed and organized activity. Facilitators are needed for proving guidance through asking questions, modelling, and explaining how things work (Gutwill et al., 2015; Petrich et al., 2013). Further, educators furnished with sophisticated pedagogical knowledge and skills are needed for integrating maker activity with formal school settings (Hsu, Baldwin & Ching, 2017). Nevertheless, the level of supporting structures vary from highly specified procedures to emergent practices in many instructional and pedagogical approaches (Sawyer, 2011). Flexible structuring is based on the idea of scaffolding (Wood, Bruner & Ross, 1976); that is, providing students contextual guidelines or supporting structures for carrying out more complex activities that would otherwise be difficult to achieve. The scaffolds vary from technical scaffolds (worksheet, mind map) to social scaffolds (such as prompts, gestures) facilitated by teachers or peers. Instead of pre-established scripts and pre-set procedures, the practical implementation of emergent processes of nonlinear invention process requires teachers to balance the structuring of a project with a flexible response to the ideas and practices that emerge throughout project (Sawyer, 2011).

Ensuring that design and making activities lead to the intended learning outcomes requires pedagogic planning, teacher engagement, and professional-collaborative learning supported by researchers. While non-linear pedagogy calls for proactively organized team learning, iterative exploration, and systematic harnessing of failures as learning opportunities, teachers have a critical role in orchestrating such collaborative efforts. Sawyer (2011) characterizes the adaptive process of the required creative teaching and learning as “collective improvisation,” guided by being embedded in and happening along the teachers’ practice. They have to create adaptive supporting structures and provide flexible, on-demand scaffolding in response to each student team’s unique situational needs. Adaptive structures refer to the scaffolding provided throughout the learning process for facilitating collaboration and creativity. To facilitate creativity, teachers need to have a clear conceptual and practical understanding of non-linear invention processes, how they are likely to unfold in the classroom, and how they can be deliberately fostered. Productive orchestration requires that the teachers have a clear vision of how instructions or given tasks affect and shape longitudinal design and making processes in embedded settings. According to Sawyer (2018), it is critical to foster focused creativity—too-open design tasks may allow students to fall into familiar patterns or frustration instead of creating new ideas and objects. Simultaneously, the emergent aspects of creative inquiry should be supported both by teachers and peers.

It appears crucial to provide sufficient structural support to facilitate students’ designing and making processes in order to unleash their full creative potentials during the complex invention project. In the context of computer-supported collaborative learning (CSCL), Lakkala et al. (2008) distinguished the epistemological (e.g., creative working with knowledge), cognitive (e.g., modelling inquiry), social (e.g., structuring of collaborative activity; Bielaczyc, 2006), and technological (e.g., digital tools available) infrastructures needed for fostering knowledge-creating learning. These dimensions are the building blocks of the pedagogical infrastructure framework, which Lakkala et al. (2008) define as conditions that were designed and implemented in an educational setting to support learning through targeted knowledge-creation practices. In this study, the notion of pedagogical infrastructure is employed as a metaphor for examining how design and implementation of nonlinear maker-centered learning was organized in the present maker educational setting. While Lakkala et al. (2008; see also, Scardamalia & Bereiter, 2006) argued that educators need to encourage learners to treat conceptual ideas as something that can be jointly improved (epistemological infrastructure), maker-centered learning extended this approach by highlighting importance of creating materially embodied artefacts and the socio-material intertwining (Orlikowski & Scott, 2008) of idea-centered and materially embodied activities in makerspaces. The term “co-invention” is used here to characterize artefacts created during students’ knowledge-creation projects, consisting of intertwined collaborative design and making processes. The purpose of the present investigation was to examine pedagogic infrastructures characterizing three cycles of design experiments concerning maker-centered collaborative learning at lower-secondary educational settings. We examined how epistemological, scaffolding, social, and material-technological infrastructures were implemented across the iterative experiments.

Methodology

Three cycles of co-invention projects

In order to implement and develop maker-centered learning in school settings, we organized three co-invention projects in one lower-secondary school in consecutive springs of 2017, 2018, and 2019. These were part of a larger research project, in which similar projects were organized in ten elementary or lower secondary schools around the great Helsinki area, Finland. The school under study emphasized craft and technology education, holding technology-focused classes for which students were selected through an entrance examination. In the first year, three participating classes were standard class and one technology-focused class (N=70). For practical reasons, only students studying at the technology-focused class participated the project at the second and third year (N=18 in both years). The idea was to focus on developing pedagogical design as well as cross-age tutoring practices in one class. All the successive cohorts of participants taking part in the present project studied in Grade 7 (aged 13 to 14).

The three successive projects investigated provide a good example of educational design-based research (DBR) (Collins, Joseph & Bielaczyc, 2004) with evolving cycles of pedagogical arrangements in one school. In the spirit of research-practice partnership (Coburn & Penuell, 2016), the projects were designed in close collaboration with the teachers according to the practical constraints of school activity. The co-invention challenge, co-configured between teachers and researchers, was the same across the three years: "Invent a smart product or a smart garment by relying on traditional and digital fabrication technologies or other programmable devices or 3D CAD." The projects were initiated in February and involved eight to nine weekly co-design sessions (90–135 minutes per session) during March, April, and May. The students worked in co-invention teams throughout the project.

As crafts is a standard school subject in Finland (Porko-Hudd et al., 2018), two weekly craft lessons were used in the projects. In addition, lessons from other school subjects were used and the integration of the subjects varied each year. In order to assist teachers in dealing with emergent challenges of applying unfamiliar technologies and nonlinear pedagogy, we relied on *team teaching* methodology, where two or more teachers work together in planning and orchestrating learning activities as well as assessing and supporting students' teamwork. During the first project year (2017), two craft teachers orchestrated the project in collaboration with two other teachers, a science teacher and an Information Communication Technology (ICT) teacher. Until now, Finnish craft teachers used to specialize in either textile or technical crafts (Porko-Hudd, Pöllänen & Lindfors, 2018); the two participating craft teachers represented both specializations. In the second project year (2018), the visual arts teacher actively worked with craft teachers whereas the science and ICT teachers were involved only when their expertise was needed. In the third year (2019), the ICT teacher and the science teacher had more central roles in teaching microcontroller programming.

The school had already established practices of using older students as tutors for younger peers. By taking part in the present study, the school aimed at creating a more systematic practice for cross-age peer tutoring. In the present study, Grade 8 students from the technology-focused class tutored their younger peers; in the second and third years, they represented students who had already completed the co-invention project themselves in Grade 7. In addition, the Innokas network (innokas.fi/en) offered support with digital instruments, materials, and coding to the tutor students and, when required, to the inventor teams. The teachers were provided systematic, hands-on training on digital instruments and participatory training of nonlinear pedagogies related to invention processes. In 2018 and 2019, three pre-project workshops were organized, where all teachers participating the research project planned their school projects in teams and received feedback from colleagues and researchers.

Data collection and analysis

A multi-method approach was used for analyzing results of the maker-centered learning practices in order to grasp the systemic features of the maker pedagogies. Each year, we collected video data of five student teams' making activities. The student teams' work was also documented in their sketches, digital portfolios (2018 and 2019), and photographs of final products. The digital tutors and the participating teachers were interviewed in 2017 and 2018. In addition, design assignments and other guidelines for supporting the students' ideation and designing were utilized to support the data analyses. We looked at the practical arrangements of the projects, including social settings and technological and material resources provided for the students. Moreover, in our qualitative meta-analysis, results from our previous research on co-invention processes were utilized (Riikonen, Seitamaa-Hakkarainen & Hakkarainen, 2018; Mehto et al., 2020; Tenhovirta, Korhonen, Seitamaa-Hakkarainen & Hakkarainen, in review). Methods of video analysis were applied to trace student teams' co-invention processes (Derry et al., 2010; Riikonen et al., 2018). The teachers' semi-structured interviews were examined using qualitative content analysis (Saldana, 2015) to find factors affecting the outcomes of team teaching in the context of co-innovation projects. The semi-structured interviews of the 15 peer tutors concerned their tutoring experiences and the challenges encountered. The tutors' skills, motivation, and challenges were analyzed through conducting qualitative analysis of the interview data (Saldana, 2015) on Atlas.ti by relying on a theory-informed and data-driven approach. Table 1 presents the dataset that formed the basis for the present qualitative meta-analysis.

Table 1. A summary of data collected

Data collection	**2017**	**2018**	**2019**
Video data	5 teams' entire design and making process	5 teams' entire design and making process	5 teams' entire design and making process
Project outcomes	Sketches, final outcomes	Portfolios, final outcomes	Portfolios, final outcomes
Teacher interviews	5 teachers	3 teachers	
Tutor interviews	Semi-structured interviews (N=15)	Semi-structured interviews of peer tutors and tutoring model	

The qualitative meta-analysis performed resulted in the pedagogic-infrastructure framework presented in Table 2. The framework was inspired by Lakkala et al. (2008); however, the present maker-centered learning context, as separated from more discursive CSCL, required some modifications. Rather than "cognitive" infrastructure, we address "scaffolding" infrastructure, including not only epistemic but also embodied and tangible support. Furthermore, we propose a broader concept, "material-technological infrastructure," for defining both the technological and material conditions of the educational setting—the combined low- and high-tech capacity of maker education that supports designing, prototyping, and evaluating ideas and artefacts.

Table 2. Pedagogical infrastructures: components, definitions, and essential features of the setting

Component	Definition	Essential features of the setting
Epistemological	**Operational practices of knowledge-creating learning** and the **nature of epistemic processes** that the assignments promote	**Iterative design and making of co-inventions:** Making advancement visible through sketches, prototypes, final products
Scaffolding	**Designed tasks and epistemic and embodied scaffolding structures for** promoting students' capabilities of engaging in nonlinear invention process	**Nature of design tasks:** design briefs and design constraints **Scaffolding for designing:** guidelines relevant for design and making **Teachers' and tutors' support**
Social	**Arrangements to organize** students' team collaboration and social interaction **Shared responsibility**: tasks defined in a way that the accomplishment requires shared responsibility	**Physical and social arrangements** of organizing productive teamwork and interaction **Shared process and object:** the focused collaborative activities and outcomes **Team-teaching practices**
Material-Technological	**Providing** technical advice to the participants and organizing the use of technology. **Functionality of** the tools and their appropriateness for the desired activity	**Techno-material tools and their functionality**: various tools for designing and constructing **Appropriateness of the tools and materials** for the desired activity

Results and discussion

Maker-centered co-invention projects may be experienced as challenging, both by students and teachers, since they involve working with unfamiliar digital fabrication technologies, encountering unanticipated construction problems, and carrying out designing and making to unforeseen directions. In the following section, we present the results, starting with the epistemological infrastructure and scaffolding of the projects. We continue with social and material-technological infrastructures and provide some examples of the data to highlight our interpretations.

Epistemological infrastructure: Engaging students in practices of design and making

The epistemological infrastructure involved in engaging students in knowledge-creation of associated iterative designing and making processes. The design task was open-ended and the teams were given complex, ill-defined tasks to solve through practices that were explicitly and purposefully aimed at creating new co-inventions. The video data revealed that students analyzed, ideated, evaluated, and refined design ideas repeatedly during the project (Riikonen et al., 2018; Mehto et al., 2020). The focused pursuit of knowledge-creation required students to actively work toward a joint epistemic object, listen, understand, and help each other during the process as well as to engage in shared efforts of testing and constructing artefacts (e.g. Barron, 2003).

The given task guided students to iteratively assess and refine their initially fuzzy ideas and finally come up with locally valued co-inventions. The process involved iterative refinement of conceptual ideas through embodied activities of making mock-ups, prototypes, and final products with tangible materials and tools. Teams of student needed to explicate, externalize, and share their emerging design ideas. In other words, *advancement* of invention process was made visible to others and required several cycles of revision and reflection, which sustained improvement of shared and *tangible objects*, such as prototypes and final co-inventions (Mehto et al., 2020). Table 3 highlights the variety of co-inventions made by the student teams. Most teams developed well-articulated design ideas, produced visualizations and prototypes, and tested and refined their co-inventions. Nevertheless, not all design ideas proceeded to final products; especially in the first year, some of the co-inventions were developed only to the prototype stage and one team failed almost completely.

Table 3. Examples of student teams and their co-inventions in 2017, 2018, and 2019

	Name	Team	Basic idea
2017	Bike	3 boys	A three-wheel bike containing smart technologies, such as an environment responsive, rechargeable LED lighting system
	MGG	4 boys	MGG (Mobile Gaming Grip), a pair of handles that improves the ergonomics of a mobile phone while playing games
	Moon	6 girls	A smart outfit for sports, including an environment-responsive lighting system to improve safety
	UrPo	6 boys	A smart insole for sport shoes, including an automatic warming system for winter sports
	Plant	7 girls	An automatic plant care system incorporating decorative elements
2018	Banana light	2 boys, 2 girls	A banana-shaped bending light that attaches to the laptop screen and lights the keyboard.
	Flabe beanie	2 boys, 1 girl	A beanie with an automatically controlled warming system
	FoxFriend	1 boy, 2 girls	A 3D-modelled fox that plays music, talks, and conveys emotions with its LED eyes
	NEObag	2 boys, 1 girl	A backpack with several integrated features controlled by Micro:bit, such as compass, temperature, phone charger, and speedometer
	Smart pillow	1 boy, 2 girls	Smart pillow, with LED lights, snoring detector, and ability to play sound and music
2019	Button Presser I	2 boys, 1 girl	A devise that can be used to press buttons automatically, controlled by Adafruit Circuit Playground Express and a servo-motor
	Moisture sensoring flowerpot	3 girls	3D-printed flowerpot that monitors the moisture level of the soil and notifies using light when the plant needs watering

	Adjustable ruler	1 boy, 1 girl	A 3D-printed ruler that has 6 parts that can be attached to each other with magnets to form different shapes
	SleepSound	2 girls, 1 boy	An ergonomic pillow with inbuilt speakers to play music or other sounds
	Sunny	2 girls, 1 boy	A power bank that utilizes a solar panel and has a 3D-printed case

Figure 1 presents team UrPo's iterative process activities during the development of a smart insole (left) and its various external visual or embodied representations (right). The chart on the left was constructed from the video data by classifying all the team's design activities in 3-minute intervals (See Riikonen et al., 2018 for details). It clearly indicates that the nature of the design process was iterative, yet still progressing. The team produced several tangible prototypes and sketches of alternative structures of the insole, especially elaborating on the placement of the microcontroller.

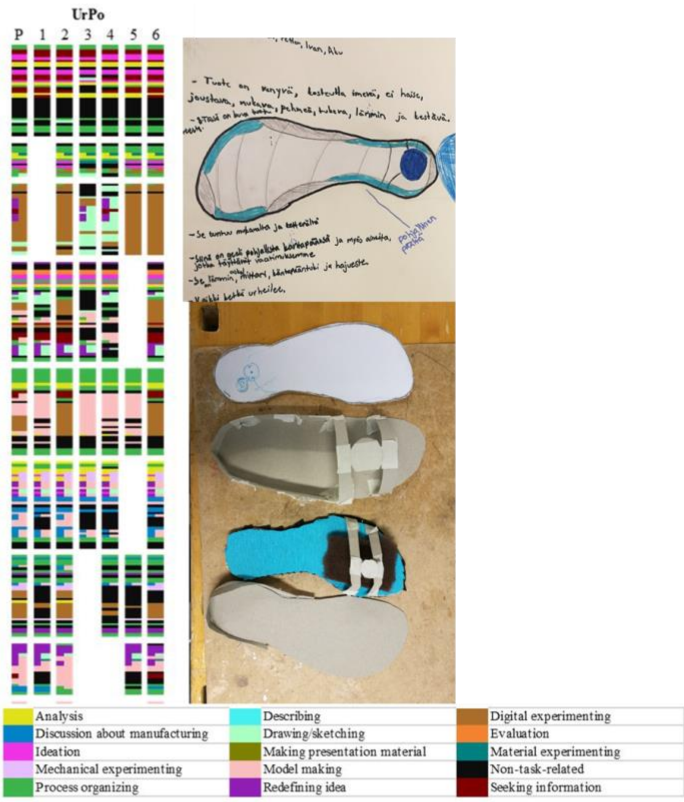

Figure 1. UrPo team's iterative process activities during the co-invention project (left) with some visual and embodied representation produced (right).

In all co-invention projects, the student teams acquired important experience of progressive design and making processes and were able to create unique solutions using both traditional and digital fabrication technologies. Co-inventions can be designed only through repeated iterative efforts, overcoming obstacles, and repeated failures with practical experimenting, obtaining peer and expert feedback, trying again, and ending up with outcomes that may not have been anticipated in the beginning. Further, the students gained confidence in their own ideas and learned to communicate and share them.

Scaffolding: Design tasks, support structures, and nature of knowledge resources

The scaffolding infrastructure was embedded in the design brief and sub-tasks that included the respective support assisting the co-invention process. The maker-centered learning setting provided structures and sequences of continuous working across stages that were self-organized by the teams during the entire design process. The design task itself was a very plain and prototypical example of an open-ended design task in terms of asking one to “invent a smart product or a smart garment by relying on traditional and digital fabrication technologies, other programmable devices or 3D CAD,” leaving lot of space for exploring the object of the invention. The task emphasized shared process and team-level objective in terms of indicating that each team should come up with one unique design.

At the beginning of the ideation, various creativity methods were used to stimulate students’ ideation and inspire design and making. In the first year, the project was initiated with a two-hour ideation session arranged in collaboration with the Finnish Association of Design Learning. During this session, the students self-organized into teams and constructed the preliminary ideas of their inventions. In the following years, the students visited the Design Museum and in the last year, the visual art teacher gave a presentation of the 5 E’s (esthetics, ergonomics, ethics, ecology, and economy) of designing. Table 4 summarizes various methods employed to spark ideation.

Table 4. Various scaffolds provided to students

2017	**2018**	**2019**
Workshop by the Finnish Association of Design Learning	Visit to the Design Museum in Helsinki	Visit to the Design Museum in Helsinki The art teacher’s presentation of 5 E’s (esthetics, ergonomics, ethics, ecology, and economy)
Ideated individually with post-it slips, together on the common big paper	Creation of individual mind map of invention 8x8 method based on each member’s own interest and then the whole team common interests	Grouping method in forming teams with name and logo Quick brainstorming method to spark ideas
Digital technology workshop	Digital technology workshop	Two digital technology workshops Electricity workshop (copper tape circuitry) Coding practice with the math teacher
Cross-age tutoring (N=15) from 8th graders	Cross-age tutoring (N=6) from 8th graders	Cross-age tutoring (N=6) from 8th graders
Collection of sketches, prototypes etc.	Group ePortfolio (Sway) with some structure	Group ePortfolio: structured guidelines, facilitation by the Finnish teacher

The actual process began in 2018 and 2019 with ideation sessions led by the visual arts teacher, after which the teams moved to prototyping in their own pace during crafts lessons. The teachers emphasized the iterative nature of designing by encouraging the students to experiment with their ideas. They did not accept the first ideas the students presented but encouraged them to redefine various ideas by testing them. In 2018 and 2019, the students were instructed to record their working on teams' e-portfolios. During the designing and making, both craft teachers provided their expertise and contingent scaffolding (negotiation with materials and representations; technical consultation). The teams mainly organized their processes independently, seeking assistance from the teachers only when needed. Only in instances in which students could not determine how to proceed or became distracted by non-task-related activities did the teachers step in to direct them. During the second and the third year, students' management of the working time was far better than in 2017.

Developing the Peer Tutoring Model for facilitating maker-centered learning

Developing the *Peer Tutoring Model* for supporting maker-centered learning was a fundamental aspect of the school's pedagogical approach (Tenhovirta et al., in review) and provided critical scaffolding structures and practices together with the teachers' support. Each year, before starting the actual project, Grade 8 student tutors arranged digital technology workshops (GoGo Board and Micro:bit microcontrollers) to familiarize each participating 7th Grade class to affordances of digital tools. The workshops fostered ideation on how programmable devices could be utilized in the inventions (Ching & Kafai, 2008). During the project, the peer tutors were present in the classroom, helping the teams with problem solving, troubleshooting, and further developing their ideas.

The original plan for cross-age tutoring was to have an entire grade 8th class as tutors (15 students). The tutors only received a 2-hour training, which made the work very challenging for the less skilled students. Four students voluntarily started, in turn, to spend their free time for improving their skills in programming and became the coordinating "expert" tutors. Although functioning in a role of peer tutor was considered motivating and provided positive prosocial experiences of helping others, the tutors were busy assisting the many tutee teams. In the interviews from 2017, most tutors desired more structured and better supported peer-tutoring processes. The coordinating tutors desired to improve the tutoring system and took an active role in training the next cohort of tutors. To that end, they selected six students from the first tutee group and provided deeper computational training, following which they taught new groups of students together. Slowly, during spring 2018, the coordinator team started to step back, giving the new tutors more space to learn and teach when they entered grade 8. The third cohort of digital tutors took more responsibility for the entire co-innovation process in 2019: they were more involved in the teams' designing, providing their expertise on technology, but also challenging and encouraging the teams to develop their co-inventions further. Their motivation was very high, they received more training and possibilities to teach also teachers and students in other schools or workshops.

The tutors appreciated the independence and responsibility they received:

> *"It became a relationship of mutual respect, because we tutors started to appreciate the job they did after trying it out ourselves, and they respected our commitment. I see this as*

> *the key. The reason was our commitment and also that of our teachers. They supported us by letting us decide on our own."* For some, the tutoring experience had even more far-reaching effects: *It has also had a positive effect on our future plans by, for example, clarifying our study paths. For me, it made really clear that I want to follow technological discoveries in medicine, and it made me choose to go to science and technology class in high school."* The tutors operated like professionals in the field, and through this genuine initiative, advanced a personal identity situated within the domain. As the craft teacher and the principal of the school put it: *"Tutoring model enables students' participation in the school's operation at various levels. It creates a positive, appreciative, heart-to-heart atmosphere in our school."*

Social infrastructure: Arrangements for collaboration and interaction

In this section, we will address social infrastructure enacted in maker-centered learning projects in terms of examining how the teams were formed, the socio-material working space organized, and teamwork processes organized and supported by teachers. When wanting to design successful pedagogical approaches and practices, it is essential to understand how students participate and collaborate in a small group setting with open-ended design and making processes. Small-group collaboration has been investigated rigorously, especially from the perspectives of collaborative talk and actions (Ching & Kafai, 2008; Buchholz, Shively, Pepper & Wohlend, 2014; Kangas et al., 2013). In order to address an invention challenge successfully, a team must simultaneously manage the design task and organize their work processes (Barron, 2003; Kangas et al., 2013); however, they were free to self-organize their working. Although the instruction of co-invention project highlighted collaboration, it was often necessary to divide work because of varying skills and limited number of tools. In such conditions, activity and interaction focused on attaining socially shared objects is likely to facilitate advancement of the co-invention process. Thus, appropriate social and physical settings facilitate participation and sharing of ideas, organize the design process, and support the emerging commitment to a shared object invention.

Students' teamwork

Based on the video data analysis from year 2017, the students focused on collaboration and shared responsibility most of the time. Nevertheless, there were differences in how the teams organized their division of labor during the project. Some teams emphasized the importance of mutual understanding, and, accordingly, encouraged each other so that everyone's voice was heard. On the other hand, there were instances of an individual student taking a leadership role, but that was not the general pattern. While the smaller teams (Bike and MGG) worked throughout the whole process in very intensive and close collaboration, the process was more scattered in the larger teams (Moon, UrPo, and Plant) (Riikonen et al., 2018). The collaboration was more democratic and balanced in the smaller than in the larger teams, and there occurred a considerable amount of off-topic talk indicating that not all members were occupied enough. Especially during the first project year, some teams were quite big and had challenges related to project and time management. The following teamwork situation of the UrPo team, illustrated in Figure 2, is a good example of the difficulties that the bigger teams faced with process organizing and focusing on the task. One of the group members, Craig, has already left the table to talk with a friend from another team. Another team member, Robin, is sitting away from the rest of the group and not engaging in the teamwork. The remaining four team members are socially engaged but simultaneously carry on two different conversations across the table. Bob tries to engage Ray in the design task, while Kevin and Jared are having non-task-related conversation. With everyone talking over to each other, the conversation is very scattered. Bob tries for a while to get Ray working with him on the design task but gives up and all four carry on non-task-related discussion:

Bob: Ray, what kind of an insole would you like to design?
Ray: I don't even have paper!
Kevin: Jared, I'm mimicking Elixir Pump!
Bob: Take some paper from Craig, he doesn't need two.
Jared: I never use Elixir Pump!
Ray: See, I actually have some [paper].
Bob: But take the shoe also from Craig!
Ray: I don't have a pen.
Jared: How on earth did you do that [a mimicking sound that Kevin made]?

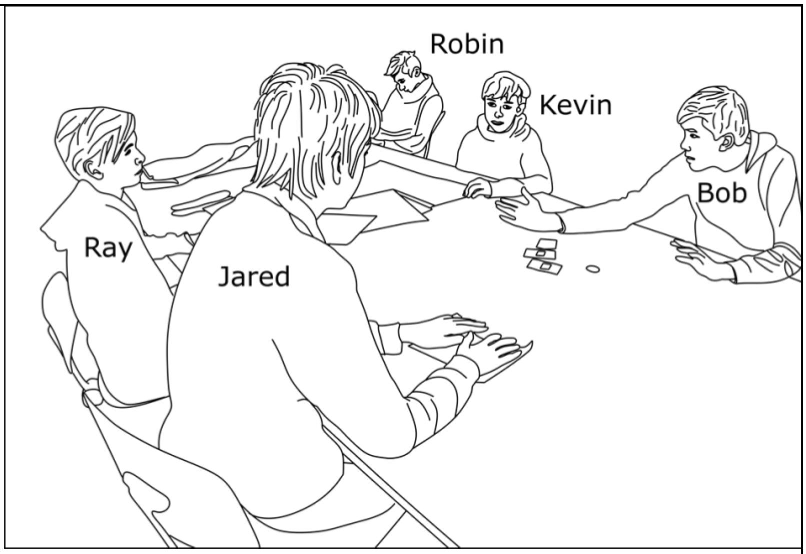

Figure 2. Example of difficult teamwork situation of the UrPo team.

Findings indicating that team size had a significant effect on the nature of peer collaboration led to the reduced team size during the second and third years and, consequently, the teamwork became smoother and more focused. In the first year, the visiting designer let the students to form teams by themselves. Consequently, uneven and big teams, up to 6–7 members in each, were formed, consisting of girls- or boys-only teams with best buddies together. Later, the teachers were encouraged to allow only 3–4 member teams. In year 2018, the teachers organized a lottery in order to form reasonable sized groups consisting of both genders. Not all pupils were, however, willing to work in such random teams, leading to some conflicts. Hence, some teams were rebuilt to provide a good start for the project. There were two students who wanted to work on their own idea, which they had invented before the project had started, and they were allowed to do so. In the third year, the teachers carefully planned and formed the teams before the project started. Teaming up was also supported with the grouping method, during which the students created a team name and a logo.

Team teaching

The collaboration between the teachers played an important part in negotiating scaffolding and orchestration challenges of the projects. During the first year, the initial plan was to engage all five subject teachers in the process, but this both turned out to be hard to arrange in practice and all the teachers were not needed in all stages of the process. Therefore, the teachers' teamwork structure was developed further. In the last year, the structure included "three layers," where the craft teacher led the team by organizing schedules and informing others in the first layer. In the second layer, both craft teachers and the art teacher orchestrated the process and were responsible for planning and implementing the project. Finally, in the third layer, the ICT, math, physics, and Finnish teachers provided their expertise to the student teams when needed.

Based on the teachers' interviews, co-planning was practiced through ideation, organization, and evaluation of the project. The teachers experienced joint ideation as an empowering method for planning both learning contents and methods. They also seized co-planning as an opportunity for project organizing, scheduling the project, and dividing responsibilities among the teachers. In addition, the teachers felt that collaborative evaluation of student work increased objectivity. They felt especially challenged, however, by the limited time allocated for co-planning sessions:

> *"-- we meet in the passage or visit each other's classrooms in the middle of a lesson, so that we don't have time, like, for breaks or anything. If we want to develop this further, it is important have co-operation time, or what it is, then it would be possible to really share experiences with a colleague undisturbed*." (Teacher 3)

> *"And then [we need to design] the contents of this project and how we are going to proceed. But now it kind of develops on the way. It develops according to how we make progress. Yes, during many breaks and many days when we work close to each other, I run there or she (another teacher) comes here, she comes here to ask, we take the time [to co-operate]whenever possible."* (Teacher 1)

Nevertheless, the teachers ensured that the established school practices and engaging team-teaching culture supported the planning of co-invention projects. Teachers reported having very fluid practices of team collaboration in terms of assuming various roles—for example, that of leader or organizer of practicalities—based on contextual needs. The key was to end up with roles that divide responsibility to each member of the team in a way that allows the students to benefit together from team teaching. Further, the teachers emphasized the key importance of sharing expertise between team members and expanding the expertise available for fostering integrative co-invention projects. The teachers felt that without cross-subject support, the implementation of co-invention projects would become much more challenging.

Material–Technological infrastructure: Availability and functionality of materials and technologies

In our project settings, the concrete tools and materials for defining, refining, and further developing invention ideas characterized the Material-Technological infrastructure. Sufficiently rich material resources and design and making tools are crucial for sparking creativity and object-driven pursuit in co-invention teams. Visual and tangible external representations in various phases of the invention process provided multi-faceted prompts for testing and refining ideas and objects generated. Hence, it is crucial to analyze how the provided tools and materials supported or hindered the production of representations.

During the co-invention project, the students worked in teams in three different studio-type classrooms: starting from the visual arts room and then moving between textile craft and technical craft classrooms, depending on what was needed for the invention process. All the spaces were well-organized, offering various resources, tools and machines, and enough collaborative working space. Together, the three classrooms provided the socio-material makerspace with diverse materials and tools needed for diverse co-inventions. In various phases of the co-invention project, such as visualizing, building mock-ups or prototypes, the teams worked with different tools and materials, using both traditional and digital technologies. All the tools and materials served certain functionality and relevance for the focused creative activity. Most of the sketches were rough, outline drawings including some written notes. The drawings were, however, understandable within the team, and they were annotated with crucial information. Interaction with materials is not only physical but spurs thinking as well. The digital tools utilized varied from one year to another. While GoGo Board and Adafruit Flora and Gemma microcontrollers were used in the first year, Micro:bit and Adafruit Circuit Playground took over during the following ones. Further, modeling with cardboard, clay, wire and other simple materials was used along with 3D CAD modeling and 3D printing. Using various materials for making the initial prototypes assisted the students in constructing 3D forms, experimenting with preliminary solutions, and examining some details on the surface (see Figure 3).

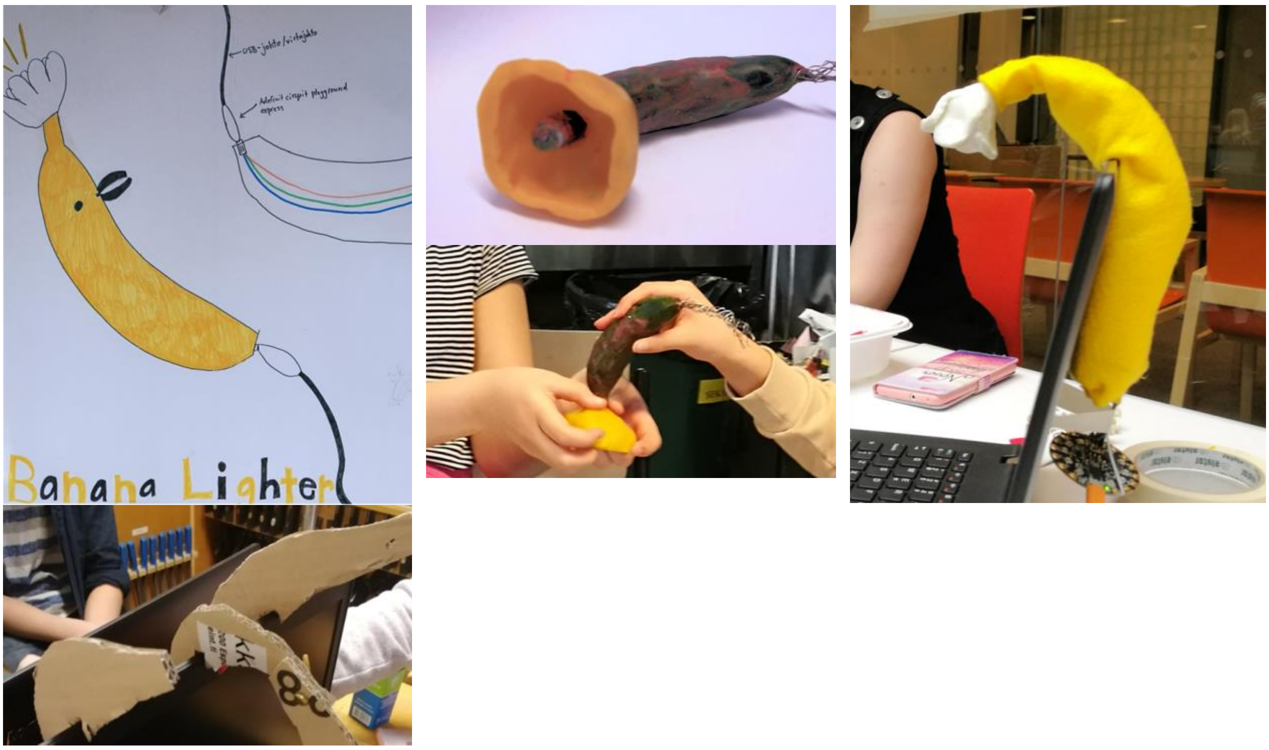

Figure 3. Various materials and tools used in different phases of designing the Banana Lighter.

However, the materials and tools used with the unscripted sessions can both constrain and enable division of labor. For example, coding with a singular laptop constrains the possibility for simultaneous participation by multiple students. This indicates that it is not only social interaction that affects the nature of collaboration but also available tools, spaces and materials play an important role during design and making.

Conclusion

The aim of the study was to synthesize findings across three successive co-invention projects. To that end, we examined the enacted pedagogical infrastructures of maker-centered learning in basic education across epistemological, scaffolding, social, and material-technical infrastructures. Overall, the present investigation addressed various critical aspects of supporting teaching and learning in makerspace settings. The design studios approach is the traditional and widely used educational model and makerspaces strongly rely on it. The central aim of studio-based working is to create a socio-material space for fostering focused designing, invention, and making of materially embodied artefacts. In the first instance, the studio method was used to provide students with socio-collaborative experience of creating inventions. Our investigation reveals that educational maker learning could be a socio-collaboratively emergent process. In accordance with knowledge-creating epistemology, the student teams transformed their ideas into various material forms and created iteratively refined artefacts according to the specific requirements of their co-invention. Further, the participants were guided to use professional creativity methods, such as brainstorming, visualizing, and materializing design ideas, at different phases of their process to assist their knowledge-creating pursuits. To make students more aware of the iterative and nonlinear nature of making, we could have more explicitly introduced some pedagogical frameworks, such as the LCD model, for helping conceptualize the iterative process of creating innovation.

Many educators (Binkley et al., 2012) have emphasized the twenty-first century skills and socio-digital competences that students cultivate in makerspaces. Fasso and Knight (2019) noted, however, that there are still no clear links between design and making practices and typical curriculum of school. In many countries, educational makerspaces have not been considered in the curricular planning. An additional problem appears to be that materials and activities included in the STEAM curriculum tend to lose the richness of socially-embedded authentic and contextual activities involved in regular makerspaces as well as focus on pursuing genuine design, invention, and making objects with emergent technologies (Fasso & Knight, 2019). Nevertheless, the current Finnish National Core Curriculum (FNBE, 2014) highlights creativity, innovation, and socio-digital skills as crucial transversal competences. Moreover, the curriculum encourages and even requires the integration of various subjects in terms of integrative or thematic study projects providing opportunities for sustaining maker culture in collaboration between the craft and other school subjects. The kinds of co-invention projects described in this study provide many opportunities for integrating various subjects and implementing transversal competences. Naturally, these requirements also create pressure for schools and teachers, as new kind of technological and pedagogical expertise and resources are needed.

Implementing makerspaces in educational settings requires fostering teachers' professional expertise, cultivating practices and methods of nonlinear pedagogy, focusing heavily packed curriculums on essentials, developing formative approaches on student assessment, and learning to use student-diversity as an asset rather than a problem (Hira, Joslyn & Hynes, 2014). However, in many cases, it is hard to find appropriate technological resources and manage rapidly changing technologies at studio-based classrooms. Designing the functioning of the makerspace requires combined expertise in pedagogy and STEAM subjects (Fasso & Knight, 2019). In our co-invention projects, there was a multi-disciplinary teacher team (including a subject teacher specialized in crafts, several other class and subject teachers) and participating teachers were provided extra support by peer tutors, researchers, visiting experts, and museum visits. Teacher collaboration interconnected various subject domains and associated expertise in nonlinear pedagogy. The analysis revealed, however, that we need to develop project documentation by providing new tools (e.g. ePortfolio) and more structural guidelines that support students or teams' reflections in and on action as well as assist in providing formative feedback.

It should be noted that the school participating in our study was an ordinary school in a middle-class suburban area, however, the school community has for years been devoted to developing practices that support transdisciplinary co-teaching and distribution of teachers' and students' technological expertise. Furthermore, in the larger research project that this study is part of, we have altogether 10 participating schools, which all are ordinary public schools with typical teachers and students. According to our experiences, developing maker-centered learning is not dependent on teachers' sophisticated socio-digital competencies, but relies more on the opportunities provided by the curriculum and the schools' structural practices.

Knowledge creation is an improvisational activity, where the best teaching is characterized as *disciplined improvisation* (Sawyer, 2018) in terms of providing a flexible space for maker-centered learning mediated by scaffolding structures and practices, such as design briefs, ideation exercises, sketching, rapid prototyping, and team presentations; it is similar to professionally performed improvisations in many areas. Further, maker-centered learning settings should provide a variety of open-ended design tasks that, among other things, provide guidance on considering and exploring user needs. Along with emphasizing the open-ended and emergent aspects of design and making, it is critical also to be focused: Too open design tasks can lead to returning to familiar patterns or frustration in searching for conventional adequacy instead of creating novel ideas (Sawyer, 2018). To conclude, the lessons learned while developing maker-centered learning practices can be crystallized as follows: 1) Emphasis must be placed on longstanding knowledge-creating projects that provide ample opportunities for sustained iterative working and learning from failures for improving objects of design and making; 2) real-time teacher and peer tutor guidance and embedded scaffolds must be used for inspiring the ideation and digital experimentation, making successively more refined artefacts; and 3) guidelines and tools (e.g. ePortfolio) must be provided for documenting and reflecting on the advancement of invention process and develop of associated capabilities, maker mindset, and creative identities.

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Material tinkering for design education on waste upcycling

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Abstract
Materials are primary elements in the process of design and are gaining more and more attention in design education. The present work illustrates the practice of material tinkering, concentrating on its effects on design education, as regards the upcycling of waste into material demonstrators, deemed to assess their possibility to evolve into sustainable artefacts. After a general illustration of the scope and objectives of material tinkering, the exposition describes the recent experiences of this practice into design schools, highlighting its pedagogical significance worldwide, and in the particular case of the Italian situation. Finally, the exposition concentrates on the specific case of work carried out in two prestigious Italian Universities (Università di Camerino and Politecnico di Milano) from 2015. The paper tries to clarify its position and significance concerning previous literature, for what appears relevant to the education of designers and for their formation in the local context to be applicable worldwide. The research method evolves from trial-and-error, typical of experimentation on materials, to the conception of material demonstrators and suitability to be applied into products, having as boundaries the choice to use some kinds of waste in an upcycling philosophy.

Keywords
DIY-Materials, Materials from waste, tinkering, materials education, teaching the experimental method

Introduction
Materials are crucial elements in the design process. As a consequence of this fact, materials education is becoming more and more significant in the field of Design, because it assists future designers in becoming more sensitive towards the expressive and functional qualities of the material. Traditionally, learning about materials has been an intellectual and book-based activity. And it is still the case in most of the Design schools worldwide, and also in Italy. On the other side, though, the recent diffusion of different approaches toward materials and the rise of specific educational and experimental tools, such as materials libraries, followed then by Fab Labs, would add tangible and practical opportunities to enhance materials knowledge in the field of Design. In more general terms, designers need continuous education about materials, because new ones are developed every day, and also since we are rapidly evolving from industrialized materials towards customized ones. This change of perspective also involves self-production of new materials in a laboratory or workshop context, due to the effect of stringent necessities, such as re-integration of waste into the production process. This process is also virtuous in the way towards educating for sustainability and suggesting ways in which products and services are matching all essential criteria of the circular model (Andrews, 2015). Materials knowledge implies internalization of facts, information, and skills, the combination of which

would be able to produce designs using material possibilities to achieve the desired user experiences (Haug, 2019).

Concerning design education, for some years, there have been studies, research and projects aimed at teaching materials to design students with an approach as close as possible to their way of thinking and designing. The concept of 'designerly ways of knowing' has been coined by Nigel Cross (Cross, 1982) as the result of reflections, which started to emerge in the late 1970s in association with the development of new approaches in design education. It is possibly expressed by saying that 'designerly ways of knowing materials' are now required and start to become available. It was introduced by research on the expressive-sensorial dimension of materials (Rognoli & Levi, 2005; Rognoli, 2010), to other works focused on materials meaning (Karana, Hekkert & Kandachar 2009: 2010). The concepts of Materials Experience (Karana, Pedgley & Rognoli, 2014; Karana, Pedgley & Rognoli, 2015) and Materials Driven Design (Karana, et al., 2015) were then proposed to give a theoretical structure to these approaches and create useful tools that could guide young designers step by step in the project with and for materials.

In parallel, various materials libraries have been developed, each characterized by different peculiarities of service and or collected materials and offering valuable support for multidisciplinary work (Dhen, 2013; Akin & Pedgley, 2015). However, they still appear very project-specific and not always suitable to enable corrections for unpredicted issues arising during the design process (Wilkes et al., 2018).

In recent years, we have witnessed the wide spreading of the maker culture and the Fab Lab[1] and that has allowed, in a fully democratic way, direct activity on artefacts and materials, above all in the field of design education (Blikstein, 2018). As consideration for the development of the concept of DIY-Materials introduced by Rognoli, Bianchini, Maffei and Karana (2015), the maker culture has spread both the idea of being able to get their hands-on materials and the place, the skills, and the tools to do it. DIY-Materials were defined as

> *"materials created through individual or collective self-production experiences, often by techniques and processes of the designer's invention, as a result of a process of tinkering with materials. They can be new materials with the creative use of other substances as material ingredients, or they can be modified, or further developed versions of existing materials"* (Rognoli et al., 2015).

The DIY-Materials are, therefore, materials designed and self-produced as material demonstrators by the designer her/himself. Often, they use rudimentary technologies obtained, through the experimentation process, with little investments and alternative raw materials, usually own waste from other production processes or materials and components at the end of their life cycle. Having recognized this emerging phenomenon in the context of international design and having studied it (Ayala-Garcia, 2019), it has undoubtedly helped its formalization as an approach and accordingly, its inclusion in the training paths of designers.

1 There are almost 1600 Fab Labs around the world. More updated information at https://www.fablabconnect.com/1600-fab-labs-worldwide/

To make the two ends meet, namely materials education and maker culture, is not obvious. Though, therefore it is suggested that a preliminary "hands-on" familiarity on the material, to assist the transformation of material didactics into participatory activities, which have a natural development into experimental materials labs and would be finally aimed to inspire the design process. The experimental process with materials was referred to as "material tinkering" (Parisi, Rognoli, & Sonneveld. 2017) Material tinkering is linked to the Experiential Learning concept, which involves the creative exploration of the connections between experience, learning, and personal development (Kolb, Boyatzis & Mainemelis, 2000). Going more into depth, this implies developing a learning method for enabling the students to acquire new knowledge through the direct experience with phenomena observed: this can be applied to the development of materials.

In particular, it is widely recognized that designers need to be educated not only in the use and function but also in the relevant technical, expressive and sensorial possibilities and potentialities of materials. Acquiring this knowledge implies a continuous dialogue and feedback between materials scientists and designers, which means that the latter would intervene into the creation of the material, but also that reciprocal exchange of suggestions would take place over time (Wilkes et al., 2016). This process can be achieved using several approaches: a general perception, recognized from the times of Bauhaus experience, is that a theoretical and book-based material education is not sufficient to provide instruments for the use of materials in design (Rognoli & Levi 2004). In contrast, the designer needs the first-hand experience of materials to apply them in a meaningful way to the design project. In other words, the theoretical study of materials science does not usually include any participatory activity (e.g., tactile experiences on materials). It can be deemed to be sufficient for well-known industrial materials, such as conventional oil-based plastics. Here, the interaction of the senses with the material is definitely limited, when not weak, being confined to sight and possibly taste, in both cases with the use of uniform colours and surface finish, and very simple and repetitive textures. The return of interest for materials, such as wood and natural textiles, which is linked to obtaining a more sustainable end-of-life scenario for products, has brought back, in turn, the possibility of a broader and more productive interaction with materials, to be translated in a "materials experience" (Karana, Pedgley, & Rognoli, 2014). The consequence is that materials selection takes place first based on their expressive and sensorial qualities. Still, on the other side, when a material has only started to be developed, it may be not obvious to evaluate what these qualities would be when having only preliminary materials samples.

The research trends mentioned above have influenced the previously described tools for material research in design. The Fablabs or incubators[2], for example, which are gradually being transformed into places where not only potential materials are developed but also the evolution of suitable models, geometries and bio-inspired solutions are considered. It has the advantage of discussing the relation between the material, and the geometry obtained, also in terms of complexity, suggesting that in some cases the link between the two can be powerful and direct. In contrast, in other situations, the same effect can be obtained almost

2 such as in the example of the Rhein-Waal Hochschule (https://fablab.hochschule-rhein-waal.de/fab-materials-en), the Materials incubator (https://www.materialincubator.com/about) and the FabLab Barcelona (https://fablabbcn.org/)

irrespectively of the material used. The latter is true for example for auxetics, where, provided the material is sufficiently deformable, it can bend in the three directions, when stretched, depending only on the internal cellular structure. New potential geometries can be reached by material-independent experimentation on single aspects, such as, e.g., kirigami cutting (Tang & Yin, 2017).

The concept of material tinkering

Design has been recognized in theory by Donald Alan Schön as a reflective practice, not different from education. The notion of “reflective practitioners” is based on the understanding that our knowing is in action, often in a tacit form, implicated in the way we act. Reflection-in-action may indicate a process through which practitioners encounter an unusual situation and have to take a different course of action from the usual or the initially planned one (Schön, 1983). On the other hand, reflection-on-action may include an analytical process, asking practitioners to reflect on their thinking, actions and feelings in connection to particular events in their professional practice (Schön, 1991). The context that encloses this reflection is that creativity can be learnt to a point provided the right instruments and processes are disposed of for the purpose (Akoury, 2019): this applies of course also to materials development and uses in design.

In particular, in recent years, it has been widely recognized as “learning by doing”, therefore tinkering around problems by “trial and error” until a solution is found, can represent a possible or even irreplaceable approach in several fields, for example in computational education (Koehler & Mishra, 2005). As suggested by Resnick and Rosenbaum (2013) “*The tinkering approach is characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities*.” This applies not only to engineering and design but also to science and engineering education. Therefore, tinkering may be particularly beneficial for multidisciplinary research (Mader & Dertien, 2016). Tinkering has the advantage to cover all kind of intuition and implicit knowledge and also recognizes that new results may embed a seed of randomness.

It can also be expressed in other terms, for example, as a Practice-led Research Process (Nimkurat, 2012). In this way of proceeding, practice is able at the same time to elucidate the research problem, offering then a context for inquiry, allowing gaining new knowledge and finally giving evidence to support research outcomes (Niedderer & Roworth-Stokes, 2007). Reflecting upon material tinkering, this implies understanding what we are looking for in a material, to which sectors of application it appears more suitable, therefore knowing better its “personality” and finally proving the point we made at the start of experimentation. In most cases, though, some modifications will need to be done to the initial assumptions. Therefore, the testing will need to be repeated by changing some parameters (recipes, temperature, time, mould, etc.). It has been recently suggested that this process may gradually lead to a sort of “Darwinian evolution”, leading to the selection of the most suitable materials for the purpose (Rognoli, Pollini, & Santulli, 2017).

The experimental approach has been revealed as an effective means of meta-learning, hence allowing the student to be aware and in control of his/her learning process. As far as design is concerned, this has been linked to the possibility to transfer the student’s expectations, by making them explicit, to the artefact produced (Winters, 2011). This method involves the opportunity to start working without a pre-conceived plan, but rather reasoning about one issue and gathering information about it, subsequently filtered through the student's own experience. This way to proceed has often been defined as "tinkering", and in some contexts, such as, e.g., museums, it has been identified as a practice useful also from the teacher's side, is an effective tool to refine frameworks for learning and facilitation (Gutwill, Hido, & Sindorf, 2015). In the case of materials, tinkering allows naturally experiencing complexity, by making connections or analogues with prior experiences, everyday life, and scientific practices, including the heuristic method of "trial and error".

Experiences dedicated to children proved successful, also for the first introduction of concepts challenging to grasp otherwise, such as sustainability, by the functional and expressive possibility to re-use waste in materials (Santulli & Lucibello, 2018). This can have an interest also beyond educational purposes, leading to a kind of "revived beauty" of the waste materials through design: of course, initial education based on tinkering can help to elucidate their potential (Bramston & Maycroft 2014; Sauerwein, Karana & Rognoli, 2017). It has been applied to several materials, resulting in the end-of-life in waste particularly tricky to recycle, such as fibreglass (Aversa, Rognoli & Langella, 2019).

As a matter of fact, "material tinkering" has been developed as a methodology in some labs around the world, with different substrates, for example with mycelium, which concentrates on growing the material with the idea to produce it in a customized way (Parisi & Rognoli, 2017; Karana, Blauwhoff, Hultnik & Camere, 2018). A definition is proposed, recognizing that "Material Tinkering is a design practice characterized by specific features, procedures, supportive activities, and goals. It aims to extract data, understand material properties, understand constraints, and recognize its potentialities. It helps to gain knowledge about materials and to develop procedural knowledge through experiential learning" (Parisi, Rognoli & Sonneveld 2017). Other experiments have different characteristics, closer to a pedagogical method to enhance the sensitivity and the education of students to the expressive-sensorial attributes of material so to facilitate its application in the design phase. In this case, therefore, the fundamental aspect is experimentation: as a consequence, the error is not perceived negatively, but rather as a possibility for the student to improve problem-solving skills.

More structured definitions of material tinkering have come out over time, which suggest other characteristics of this practice. In particular, this appears to be, as discussed above, a tool for experiential learning on the material through the application of self-production of the so-called DIY-Materials (Rognoli et al., 2015). The obtained materials have been studied to try to elucidate their aesthetics, which appears based on different principles than those of industrial materials (Ayala-Garcia & Rognoli, 2017). More specifically, the latter appear based on homogeneity and uniformity, precision and repeatability, whereas in contrast DIY-Materials. Therefore, material demonstrators originating from these, present imperfections and especially may change aspect overtime, presenting ageing and degradation, not differently from what happens to natural creatures. This has some significant connections to some material culture; for example, the ancient Japanese tradition of Wabi-Sabi exalts the beauty of the imperfect things (Ostuzzi, Salvia & Rognoli 2011). These on the other side result in enhanced expressivity and similarity to natural materials, such as it is the case, e.g., for solid wood in terms both of presence of fibres and contrast of colours, as well as the presence of aromatic scents. On the other side, the presence of flaws and imperfections contributes to the valorisation of materials, since it can be presented as a sign for personalization of DIY-Materials. It allows rebuilding the bond with objects, which does break at the moment when this starts to be perceived as "waste" for the most various reasons, which include, but are not necessarily linked, to their functionality.

In more general terms, the onset of DIY-Materials can be defined as a change of paradigm, therefore a way of thinking, which proceeds from the previous paradigm of fabricated materials, modifying some concepts. Plastics represented materials being light and easily mouldable, with no visible alterations overtime, only slightly photodegradable with prolonged exposure to sunlight. The presentation of polypropylene at its first appearance in the form of home products between the 50s and 60s does reflect this attitude of the material since the advertisements are centred on the lightweight and unbreakable character of the products (Colonetti, Brigi, & Croci, 2014). Conversely, DIY-Materials and the process of self-production would also enable the concept of sustainability entering into the picture. Since the recent indications (EU directive 98/2008 on waste) require that the first option to be explored is whether the production of waste can be avoided, it is essential to know the character of waste to integrate it effectively in new materials. This would also facilitate the production, which needs ideally to take place with the most limited consumption of energy and raw materials, with the objective to create new materials and prospective products of some success. This would contribute, by defining some more proper use, to a possible end-of-waste (EoW) strategy for the waste in an object.

If performed in this way, material tinkering can contribute to the success of the upcycling process, therefore generate more value. The use of materials derived from waste can contribute to the sustainability of product design. More difficulty has been encountered once trying to delineate a concept of aesthetics for these materials, which have been defined as *revived materials* (Sauerwein et al., 2017). It can be solved or explained by reasoning on the imperfection, as a natural characteristic of materials, especially in terms of differentiating them from plastics, seen as the paradigmatic synthetic material, and also to preserve as much as possible the visibility of waste introduced, in terms of fragments, texture or colour nuances. On the other side, there is an undeniable significance in terms of educational content, to be communicated through an appropriate educational route. In particular, using waste obliges one to reflect on the reasons for the success of a product, accordingly on its perception by the customer. Also, self-production implies that the customer and the manufacturer would possibly converge, so that a material can be produced on-demand, according to definite requirements.

The case study considered

The target of the material experience course is design students, who already have some basic knowledge of materials and production processes, in particular of what is required for an effective and compliant moulding of material, even in the absence of industrial systems. The typical duration of the experience for each student or group of students (normally no more than three are involved in the same project) is a course that lasts one semester and starts with some class lectures to start reasoning on the context of DIY-Materials, followed by workshop activities. This inevitably involves some practical home activity for the students, because many attempts and refinements are required during the process of tinkering, and also to the circumstance that often cooking or curing of the material may take some time. The leading idea was that the development of the material demonstrator through the tinkering process would have a didactical value through the learning and practice of the experimental method. A well-known link exists nevertheless between cooking and the experimental approach, in terms of stepwise development and optimization of recipes and procedures (Munari 1992).

In the experience described in the article, the concept of material tinkering is illustrated using the culinary metaphor, because it fits well with the idea of ingredients, recipes and preparation through mixing and cooking. Experimenting with materials is similar to food preparation since a recipe/method is followed and gradually improved, tinkering on it by "trial and error". It is necessary to experiment before finding the right quantities of ingredients, including how the waste is prepared to be introduced into the host "matrix", usually formed from a polysaccharide (e.g. starch) or protein (ad example whey milk). In practical terms, waste does not always turn into dust as it is sometimes convenient to use a reference to the original production system from which the "secondary raw material" derives.

Of course, adopting a "fuzzy" geometry for waste can create limitations to its integration of excess in the structure, to achieve what in engineering terms is indicated as an effective and strong "interface," i.e., with perfect bonding to the hosting matrix. It is recognized though that adapting the whole material to include waste not necessarily powdered to its finest mesh is also a part of the formative path during experimentation, since design can assist in solving this issue. Another purpose of the "trial and error" method is the optimization of the production process, which includes the cooking method, if necessary, the temperature and time for it, and the hardening phase, which led to the possible use of the material after removing excess moisture, thus avoiding the degradation process as much as possible and necessary, with consequent formation of fungi or mold.

Another problem which encompasses the whole method is the selection of a mould and attention to the two main drawbacks of inappropriate moulding. These, in particular, are the incomplete filling of the mould, and the problematic extraction from the mould. In the first case, we have the manufacture of an unfinished piece and, in the second case, the result is a damaged piece.

The result of the application of a tinkering process is not to have a finished product. However, in the literature, there are examples of experimentation experiences that come to the production of personalized DIY-Materials for different purposes (Cecchini, 2017; Ordoñez & Rexfelt, 2017). What we want to underline here is that the hands-on use of waste during projects and workshops can be important for students and design professionals to foresee interdisciplinary collaborations, aimed at promoting the industrial re-development of discarded materials.

However, here the issue is not directly linked to spreading practices for "designing from the bin", but to the creation of a "material demonstrator", which can reveal the possibilities of the individual waste in its introduction into the matrix. For this reason, some possible solutions have been frequently explored, such as aromatization with different herbs, or natural substances (e.g., sage, curcumin, thyme, etc.) or colouring with natural dyes, such as beetroot water or anthocyanin from orange peels. All these strategies are consistent with the idea of designing the perception of the material using the expressive-sensorial dimension (Rognoli, Ayala-Garcia, & Parisi, 2016).

The role of waste upcycling and the development of the projects

The starting point of the entire research considers that to obtain valid material demonstrators is necessary to use the maximum amount of waste. In the experiments conducted in the design courses of the two universities involved in the study, the use of waste from the food sector and therefore readily available and "zero km" has been promoted. It was considered appropriate to highlight two critical aspects of the possible production of materials: the first concerns the use of food waste not suitable for human consumption. The second concerns the matrix in which the waste is introduced, which must be composed with expired products. Therefore, nothing fundamental, necessary and useful is subtracted from other cycles.

In practical terms, two types of matrices were employed in this kind of experimentation, which are respectively based on polysaccharides (e.g., corn or potato starch) or protein (e.g., milk whey) matrix. In this sense, attention was taken to the use of past "best before" date products. Over four years considered (2015-2018), around 200 projects were developed, over 80% of which involved the development of a plasticized starch matrix, while less than 20% used protein-based matrix, and the main difficulty of the latter appeared the "cure" process, therefore their progressive hardening while drying.

Having said that, the only products further necessary to the recipe, which cannot be considered as waste, are the plasticizer, which are a viscous additive, such as glycerol or honey, in the case of polysaccharides matrix, or an acid solution, such as vinegar or lemon, in the case of protein matrix, to contribute to their denaturation, therefore to reduce water absorption. The two matrices used to refer to the so-called plasticized starch (Garcia, Martino & Zaritzky, 2000), often expressed in a simplified way as bioplastics, and to Galalith, a casein-based material, which is currently defined today, as some other coeval material, such as cellulose acetate, as an "early synthetic plastics" (Lokensgard, 2016). In Galalith originally denaturation was achieved using formaldehyde but can also be obtained introducing nontoxic substances, as can be the case for vegetables and seeds that have a substantial amount of protein in them, for example, lupine. As a matter of fact, the so-called "vegetable casein" was of extensive use during the last century (Chang & Chao, 1935).

The students were left free to develop their material demonstrator with the only limitation that a type of waste had to be used and enclosed in a self-produced biopolymer matrix. Following this, some criteria are given for which the waste material can be valorised in an “upcycling” philosophy, as opposed to its technical use in a generic powder form, therefore losing most characteristics that make it recognizable. These criteria can be described as follows:

- The material is not reduced to very fine powder if not necessary and is not encapsulated into a newly produced material (e.g., synthetic polymer resin, such as acrylic or epoxy).

- In the case it has particular characteristics (e.g., birefringence, surface roughness, colour, etc.) these are preserved as much as possible.

- In natural materials, the differences of shape or colour and other characteristics, for example, porosity, can be considered typical and therefore contribute to value.

- Imperfections and defects are not being considered as defects; instead, they have a part in the aesthetics of the material, as emphasized by the microscopy observation.

Results and discussion

The tinkering approach is aimed at obtaining significant experiences in the development of materials, and then at selecting the more promising materials for investigations and further developments. In these circumstances, the use of waste or scraps further complicates the matter, because it could be challenging to communicate the value of a material obtained from the recycling of scraps. Using the classification of DIY-Materials (Ayala-Garcia & Rognoli, 2017), we examine the materials considered waste because they are regarded as resources belonging to five "kingdoms": *vegetabile, animalae, lapideum, recuperavit and mutantis*.

However, in sporadic cases, students have also used sand, which belongs to the realm of the lapideum, and is a widely available waste. Furthermore, the use of sand can modify the moulding of the material. Besides, some have used cotton gauze, as waste from the textile industry, or spruce sawdust, as waste from the wood industry, both of which belong to the kingdom recuperavit, as well as the ash of spent cigarettes.

As a consequence of the above, we have developed a different but complementary classification based on the chemical rather than the biological origin of the various types of waste. In this way, the resources can be divided into cellulosic, wooden, ceramic and various.

In general terms, most of the waste used can be classified as of food origin, however making a further distinction between food waste that is inevitably produced (therefore what is not needed for human consumption, for example, eggshells, walnut shells, mussel valves, etc.) and possible food waste, the production of which cannot be avoided.

In other cases, the cellulose content is higher, and the hardness of the material is reduced. Some of these elements are used, at least partially, in some food preparations, such as in the case of orange peels, which can also be the source of particularly marketable additives (Pfaltzgraff, De Bruyn, Cooper, Budarin, & Clark, 2013).

Other types of food waste can present a particular utility, in the sense of providing a specific aroma or perfume, which can facilitate the acceptance of the DIY-Material, such as the case of banana peel waste, with the addition of anise (Galentsios, Santulli, & Palpacelli, 2018).

All the material demonstrators originate from the tinkering process of the experimental experiences narrated in the paper are represented in Figure 1. From the first considerations downstream of the experience, we have extrapolated numerous factors. In particular, we can say that the choice of wastes introduced into the matrix is influenced by:

- Easy availability. Some types of waste are available, especially in the Italian context, all year round and are usually zero km because many people, including students, often consume them. Examples of these are coffee grounds, banana fibre and citrus peel, potato peel, carrot peel, and eggshells. It can be noted that also the seasonality of food waste is significant and, some of the DIY-Materials presented here are the result of a course that has always been held in the winter semester, thus allowing also the use of shells of walnuts, hazelnuts and pistachios. Other types of shells, such as that of mussels, are not related to seasonality if not to the place (available in seaside resorts or fish restaurants). Another important factor for easy availability is also the cost, and in general, these foods are on the average cheap.

- Easy processability for introducing the scrap into the matrix. The advantages of some scraps, such as coffee grounds, are that they can be reduced to powder or in any case, as in the case of orange or banana peels, they can be easily cut. It contributes to the regularity of the waste form introduced into the matrix. In other cases, as for the wooden shells (from the seeds) or ceramic (from the mussels), the fragments are less regular. It, on the one hand, offers more expressive possibilities, also in terms of colour shades and disorganized textures. Still, on the other hand, it makes it more challenging to integrate the waste into the matrix, creating inhomogeneity. This, in materials science, is defined as the creation of an "interface" filling matrix.

- Limited formation of mold or fungi. Some scraps require previous processing, such as drying in a fan oven. It is the most widespread preparation process for food waste and is applied, for example, to coffee grounds and orange peels. Another possibility is the use of herbs in the mixture, as suggested by the culinary tradition, such as thyme, cinnamon, curcumin, etc. The tinkering process has led to the exclusion of some experimentation path due to the persistence, for example, of mold, as happened with crab exoskeletons (in chitin) in a starch-glycerol-lemon matrix.

- Recognizable colour or ability to change colour. Some types of food waste, among those mentioned above, have a colour that identifies its origin. On the other side, especially in materials developed in film formats, hence with a thickness lower than 500 microns, the use of coloured water for production proved useful. This was the case for example of the already mentioned beetroot water or water from fennel or chicory boiling. Starch-loaded water from pasta or rice boiling, a typical kitchen waste, could also be proposed for use in the future, possibly after being naturally cooled down. In addition, milk whey-loaded water from mozzarella cheese preparation was attempted, as suggested by Caliendo, Langella, Santulli, and Bove (2018), which is supposedly leading to an improved hardness of the obtained material.

Figure 1. A collection of materials demonstrators self-produced by the students over a few years of materials courses. (Camerino, 2015-2018)

When tinkering with materials, evidence should always be considered. There are some basic shapes and artefacts that are more effective than the initial demonstrator for evaluating specific properties and characteristics of the DIY material. In particular, a characteristic that must be observed is the possibility of obtaining curved shapes without the gradual development of cracks in the material. Besides, checking the thickness uniformity can also be important. Both these purposes can be achieved by producing small bowls, as shown in Figure 2. It should also be considered that the moulds useful for this purpose are easily available, for example, those for cupcakes.

Other problems can also be easily experienced, such as the application of a counter-model ensuring its perfect closure on the mould with simple means, for example, a small mechanical clamp. The demoulding process depends on the material of the mould and also on the possible application of procedures to facilitate it, such as the use of silicone-coated baking paper.

Figure 3 focuses on the prevalent types of colours and shades that can be obtained. The experimental results obtained must not be described as such, since they represent only attempts to design the "personality" of the material generated by combining it with the functional or expressive properties that may be suitable for some applications. The question of gradual/loose colouring cannot, for example, be resolved with objective considerations, since there are colours easily to obtain with simple experiments, in particular those based on anthocyanins or carotenoids (reds and oranges), tannins (brownish), or natural colours of some products, such as starch or wax. During tinkering, other colours were experimented to be used rarely, as not very available. We mostly refer to shades of blue. As far as colour is concerned, it must also be taken into account that some types of waste can hardly undergo colour changes, as in the case of coffee grounds or even some fibrous or wooden waste, such as that of hemp. This difficulty has led students to focus more on obtaining different textures or nuances, which can lead to giving the material demonstrator a personalized character. In other words, their imperfection allows highlighting their naturalness and uniqueness.

Microscopic images can be of great use to better differentiate the material demonstrators and often also to present them. In most cases, we have used magnifications from 10x to 40x (Figure 4). From a pedagogical point of view, it is possible to have interesting results when the material demonstrators explain the potential of processability of the DIY-Materials itself. For example, for the creation of holes, preparing the application of low-cost devices, such as toothpicks, small pipes, etc., in the mould. The use of screws or nails instead demonstrates a specific resistance to penetration. After completing the part of the experience on the material demonstrators, it would be interesting to illustrate the relationship of the DIY-Materials between them, in terms of similarities and differences, without limiting them to colours and textures. It transcends the limits of a material library, as it is based on the subliminal perception of different DIY-Materials and helps us investigate their "personality".

To start with, tentative collective presentations of materials demonstrators’ families (those in Figure 5 are all based upon starch with the participation of different natural colours and waste types).

Figure 2 Small bowls made of "Frangile", a DIY-Materials developed by Patrizia Calcagno, Martina Carraro, and Francesca Pucciarini.

As a material demonstrator, the small bowls are suitable for the first investigation on the properties and qualities. Frangile is a DIY-Materials created using basic ingredients, like starch and sugar, enriched with flavours obtained by adding spices or food. The aim was to design a packaging made of edible materials. Because of its inherent brittleness, it can be used as a temporary object in the food industry.
Designing Materials Experience course 2014/2015, School of Design, Polimi. (photo by Calcagno, Carraro, Pucciarini))

Figure 3 Variety in the use of natural colours with tentative geometries (Camerino 2015-2018)

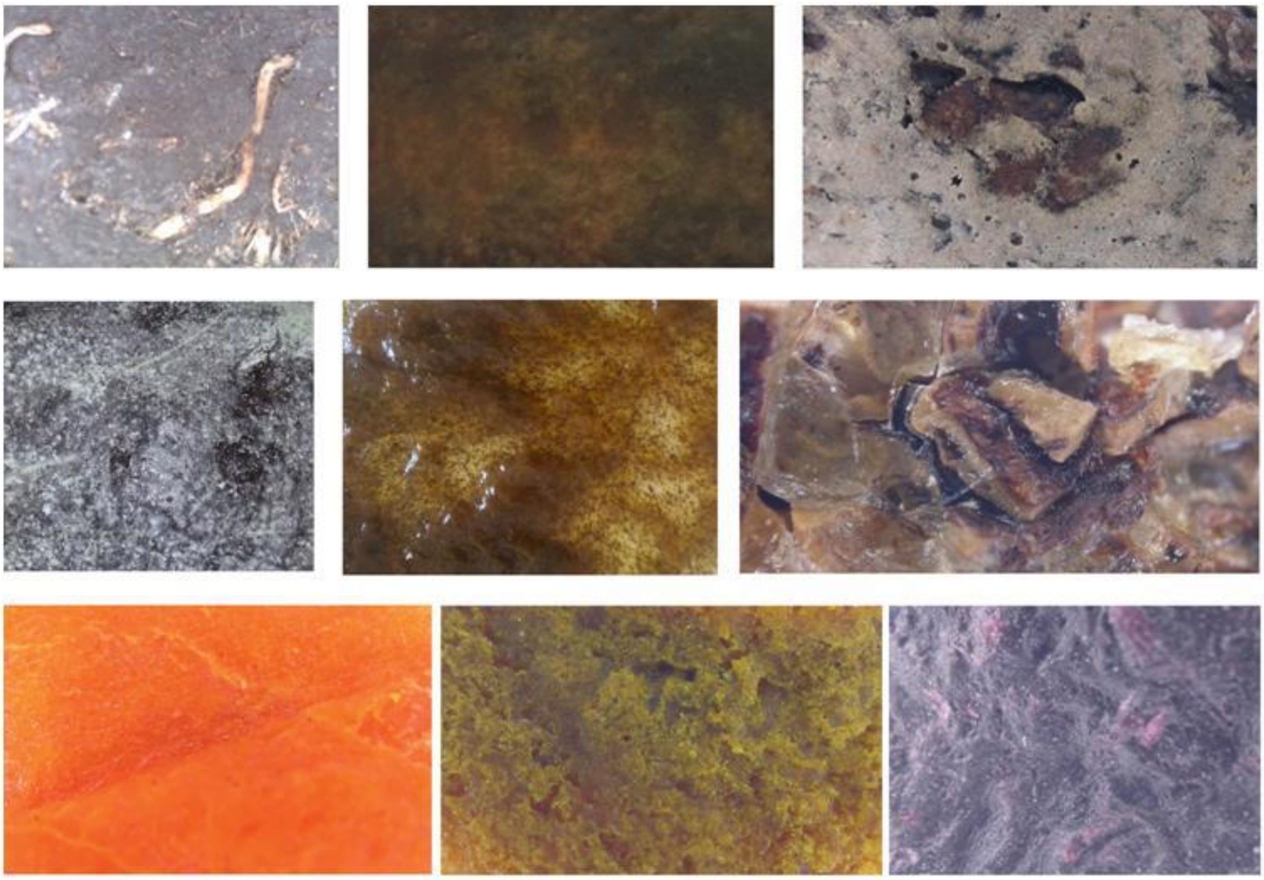


Figure 4 Examples of microscope images of materials demonstrators (Camerino 2015-2018)

Figure 5 Initial attempts for the presentation of different DIY-Materials shortly and expressively using a material mood board (CREDIT: Federica Voltattorni, Unicam)

From these initial considerations, obtained during tinkering with materials, a more precise and concrete classification of the "personality" of the single DIY-Material seems to emerge, as shown in the following figures (Figures 6-9) dedicated to materials belonging to different "kingdoms". The DIY-Materials kingdoms are useful work-tools, capable of starting the reflection on the potential of DIY-Materials, rather than closed and limited categories. The interest of this development is particularly given by the fact that in this way the possible further developments of the material are naturally proposed by the material itself, which is observed at the same time technically, functionally and expressively. This is consistent with the philosophy of do-it-yourself materials and can guide their further improvement.

Considering what has been said so far, it would seem that tinkering on DIY-Materials is to be carried out exclusively in the Fab-lab because, with these, we share the knowledge of experimentation and makers culture. However, these are not the only places to experience material. Instead, we want to suggest conducting material experiments on different scales and with different purposes (e.g. geometry, moulding, textures/colours, mechanical performance, joining, etc.). In this context, we recognise the concept of "Materials Club", a platform of skills and tools that can support students and design professionals who want to make experimentation on materials their strong point. The Materials Clubs are born from the systematisation of resources and structures for the experimentation of already existing but not exploited materials in their possibility to work in a coordinated way (Ziyu, Rognoli & Ayala-Garcia, 2018).

Besides, DIY-Materials are gradually acquiring a status comparable to the designed materials in terms of the learning experience incorporated into them. Samples of materials developed over the years by the students of the Politecnico di Milano formed the "Made @ Polimi" collection[3] (Figure 10), and they are also included in the material libraries.”

In academia and material design research contest, many people work on developing personal approaches to material tinkering. In general, all this ferment seems to lead to complementary results that confirm the authenticity and consistency of the concept of tinkering and DIY-Material and their value in the world of material education.

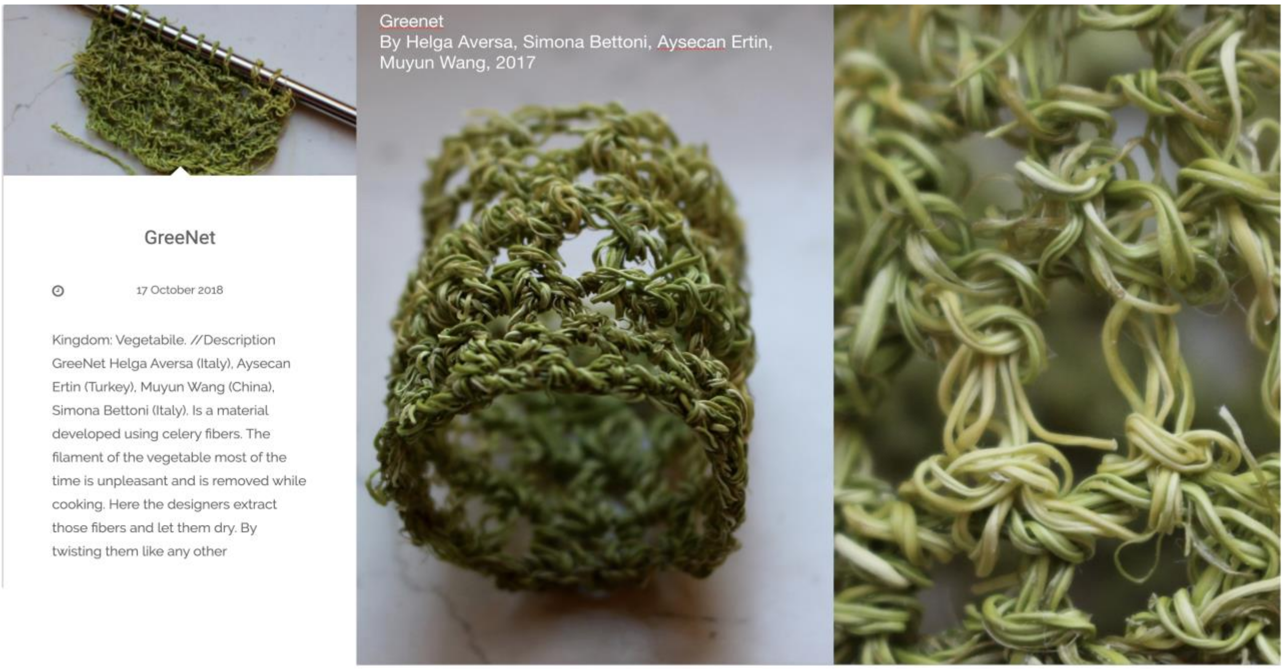


Figure 6 Greenet, DIY-Material developed by Helga Aversa, Simona Bettoni, Aysecan Ertin, Muyun Wang.

It is a material demonstrator produced using celery fibres. Designing Materials Experience course 2017/2018, School of Design, Polimi. (photo by Aversa, Bettoni, Ertin,Wang - http://www.diymaterials.it/category/made/made-polimi/)

3 http://www.diymaterials.it/category/made/made-polimi/

Figure 7 It's never too lat(t)e DIY-Material developed by Aslan Dicle, Ibrahim Dinullah, Shao Yizhuo, Unal Betul.

It is a material demonstrator produced using expired milk. Designing Materials Experience course 2017/2018, School of Design, Polimi. (photo by Dicle, Dinullah, Yizhuo, Betul - http://www.diymaterials.it/category/made/made-polimi/)

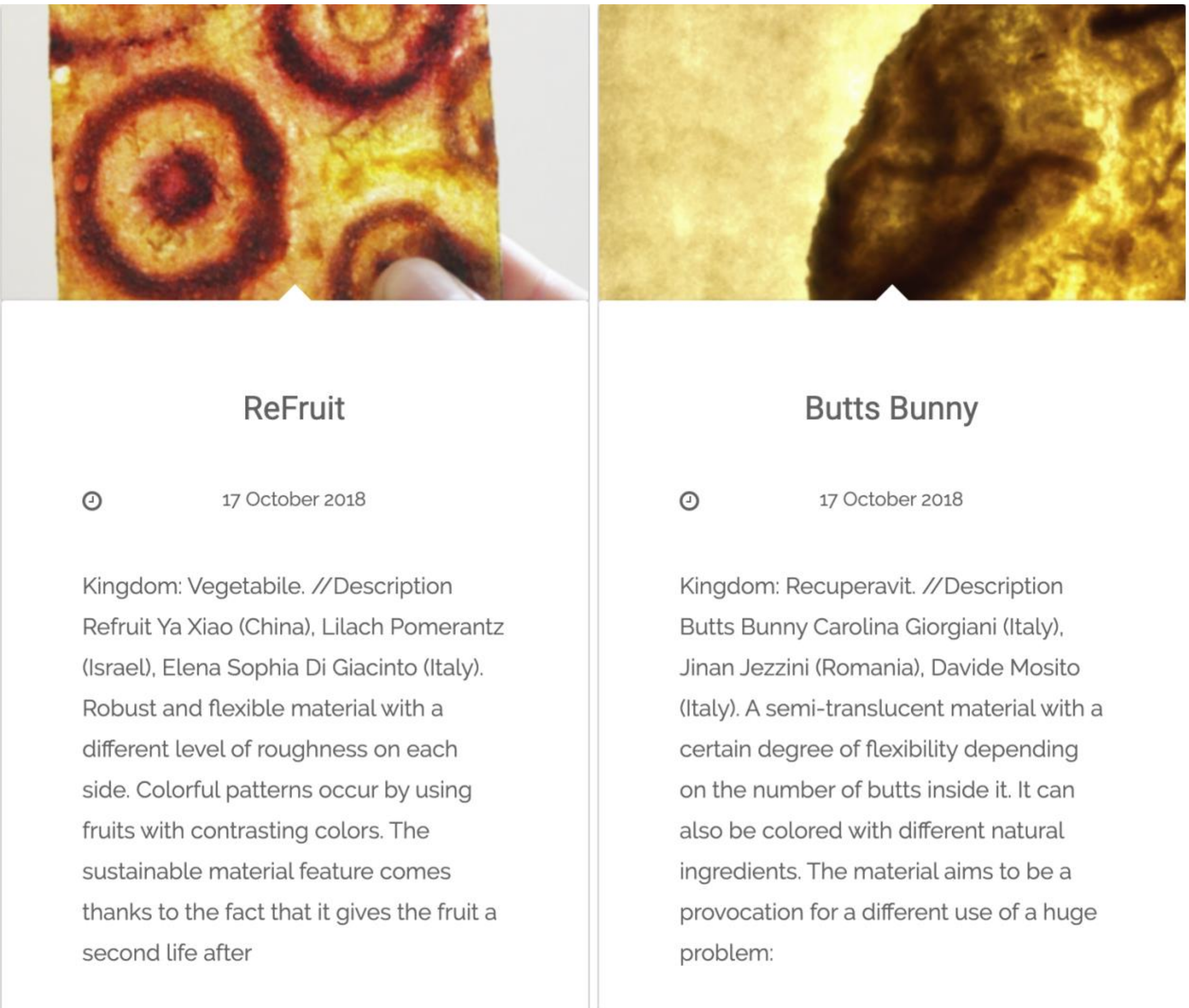
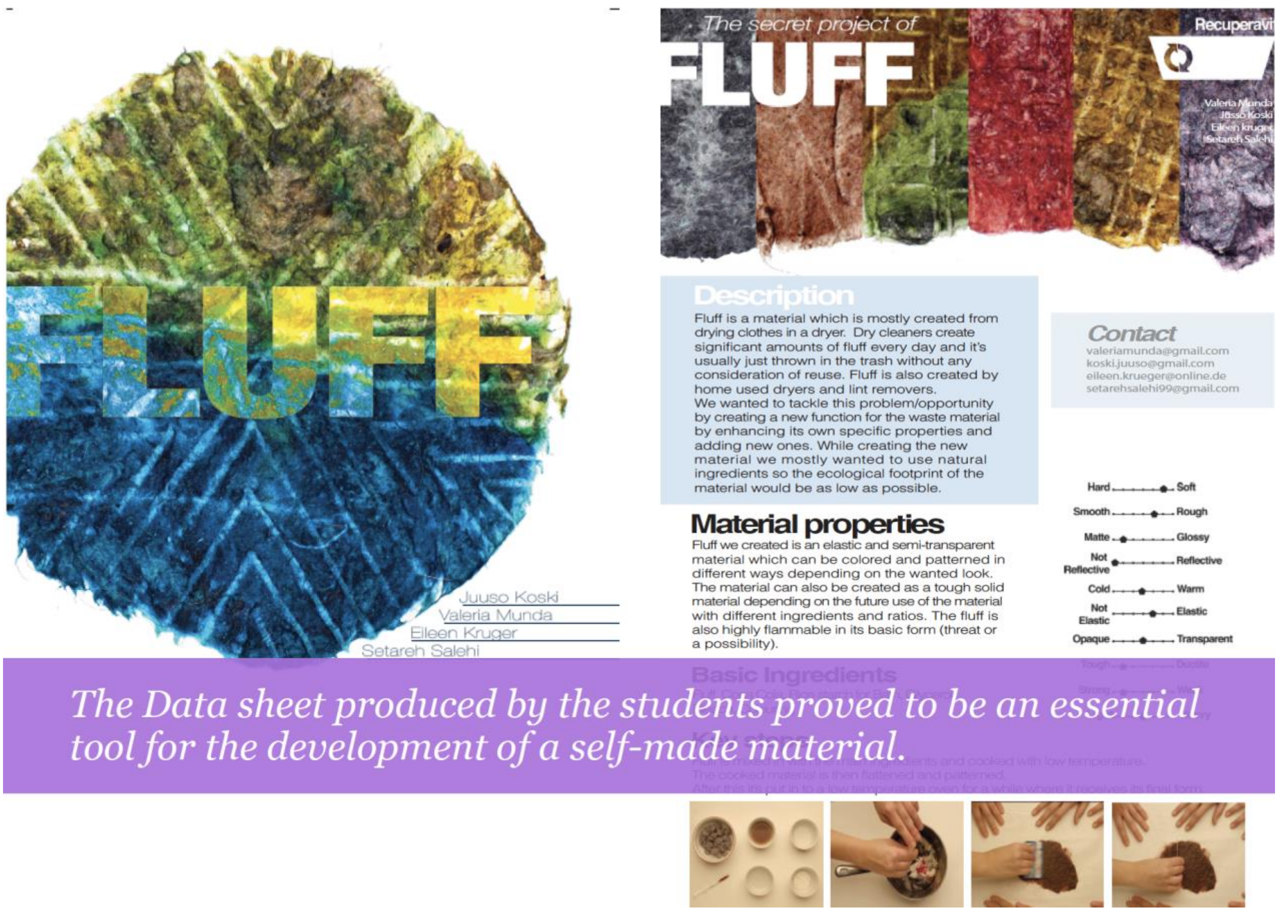


Figure 8 Two descriptions of DIY-Materials.

ReFruit is a material demonstrator developed by Ya Xiao, Lilach Pomerantz, Elena Sophia Di Giacinto using fruit waste. Butts Bunny developed by Carolina Giorgiani, Jinan Jezzini, Davide Mosito, using cigarette butts. Designing Materials Experience course 2017/2018, School of Design, Polimi. (photos by Xiao, Pomerantz, Di Giacinto and by Giorgiani, Jezzini, Mosito - http://www.diymaterials.it/category/made/made-polimi/)



The Data sheet produced by the students proved to be an essential tool for the development of a self-made material.

Figure 9 Fluff is a DIY-Material developed using the lint in the dryer machine (in Laundry services).

It was designed by Juuso Koski, Valeria Munda, Elleen Kruger, Setareh Salehi. Designing Materials Experience course 2016/2017, School of Design, Polimi. (photos by Koski, Munda, Kruger, Salehi)

Figure 10 Made@Polimi display of DIY-Materials at the materials library of Politecnico di Milano[4], 2018
(photo by Camilo Ayala Garcia - http://www.diymaterials.it/the-diy-materials-club/)

Conclusions

This paper exposes the practice of self-produced materials as demonstrators of infinite possibilities and potential. We have shown the process which, starting from the waste, thanks to the method of tinkering the materials, allows us to propose some demonstrators of materials useful for regulating on possible material experiences. In other words, the idea was to invite design students to work and design around this topic and improve the role of understanding the meaning of materials in design education, using the recycling of waste as a trigger to start the process of their transformation on material demonstrators.

After a general illustration of the scope and objectives of material tinkering, the exhibition describes the recent experiences of this practice in design schools, underlining its pedagogical significance worldwide. The work presented here, therefore, focuses on the particular cases carried out in Camerino and Milan since 2015, trying to clarify its meaning compared to the previous literature, for what appears to be relevant for the education of designers and their

4 http://www.materioteca.polimi.it/en/sample-page/

training in the appropriate local context and transposing it worldwide. The research method evolves from trial and error, typical of experimentation on materials, to the conception of material and suitability demonstrators to be applied to products, having as limit the fact of using certain types of waste in an upcycling philosophy. The materials produced can be described in engineering terms as biopolymer matrix composites and are developed in demonstrators, which can help designers know several aspects that lead to acceptance of the materials. These include colour, consistency, shape and visibility of waste, but also thickness control, effective moulding and processability. Future developments would lead to the study of the properties of the materials, the engineering characterization and the evaluation of the technological potential. These are phases in which the designer can be actively involved and not act only as a user of the technical data measured by the materials engineers, as has also been often so far. The synergy between engineers and materials designers, obtained through shared participation in the process of tinkering materials, can offer the complete perspective of the feasibility of materials, both expressive-sensorial and technical-technological.

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A Literature Review on The Use of Music in Architectural Design Education

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Abstract

In order to improve creative thinking in architectural design education, it is useful to interact with other disciplines such as music. There are many works of this interdisciplinary approach between architecture and music in the literature. These studies focus on new methods of creating forms with music for basic architectural education. The common aim is using music as a creative perspective for designing forms before proceeding to architectural design. Various structural forms designed by students are examined within these studies. It is concluded that designing with music could improve students' imagination and could be benefit to architectural design education. Furthermore, these approaches could be improved, not only in basic form design, but also to be applied in an entire architectural project from space to façade. Music could be used as an inspiration to be transformed into a product, an interior or an architectural structure, and this could be useful for architectural design studio courses. Therefore, this review aims to underline the benefit of music in architectural education by examining the existing studies in the field, and it is a preliminary research for the further study of a method of designing with music.

Keywords

Architectural education, design, basic design, music, form, concept design

Introduction

Music as a conceptual starting point, or an inspiration, could be reflected in a design. This enhances the originality and aesthetic value of designs. According to a study conducted at Oxford University, England, it has been determined that music playing at a reasonable sound level in the background increases creativity. It has been observed that the background music improves the ability of abstract thinking while working, compared to a completely silent environment. Based on this information, it was thought that the positive effect of music on creativity could improve architectural design education. In addition, creating a form based on music is useful as a method in the design process of the form. For this purpose, research was conducted to develop a method of creating forms with music in order to improve architectural design education. This study was carried out qualitatively. In this context, studies on the use of music in architectural design education were examined within the scope of the research. Bibliographic studies conducted between 2002 and 2018 were selected and examined as the subject of the research. As a result of the study, it was aimed to be an auxiliary resource to applied units and to contribute to the literature (Mehta, Zhu & Cheema, 2012).

Friedrich Nietzche emphasized the importance of music by saying that life without music will be a mistake (Nietzsche, 1889). The etymological origin of the word music has come from the Greek word "mousa" or Latin "musa". Although 'Mousa' is the name given to the nine muses in Greek mythology, it has come from the root of "men", which means "power of thought, reason and creativity" in Greek (Dönmez & Kılınçer, 2011).

The definitions of music emphasize the relationship between sound and humans. Sound only exists when it is heard by a living being. In this sense, it could be said that sound is the images of vibrations occurring in the brain (Levitin, 2015). Musicologist and academician Otto Karolyi described music as being formed by the regulation of vibrations (Karolyi, 1965). Also, music writer Ahmet Say (2008) defined music as “music is an art whose material is sound" (p. 15).

Music is a time-related or temporal art since it exists within a certain period of time (Stravinsky, 2004). Also, a transmissive environment is needed in order to hear the music (Levitin, 2015). The relationship between music and design could emerge from the similarities between two disciplines, which encouraged interdisciplinary collaborations. Architect, Designer and Musician Jan Henrik Hansen mentioned these similarities in his TEDx Zurich speech (Table 1) (URL-1).

Table 1. J.H. Hansen, Similarities between music and architecture.

MUSIC		ARCHITECTURE
VOLUME, RYTHM, TEMPO	→	SIZE, STRUCTURE, SPEED
ARRANGEMENT, COMPOSITION	→	ORGANIZATION, COMPOSITION
TONAL-RYTHMIC PROPORTION	→ →	SPATIAL PROPORTION
MESURE, QUANTISATION	→	SCALE, BREAKDOWN
NOTATION		PLAN, MODEL

Jan Henrik Hansen is an example of the relationship between music and architecture with his project "Architecture of Music". Hansen and his team developed software that turns music into form, thereby transferring the music to their designs. One of the works in this project was designed with Keith Jarrett's composition "My Song" (Figure-1,2) (URL-2).

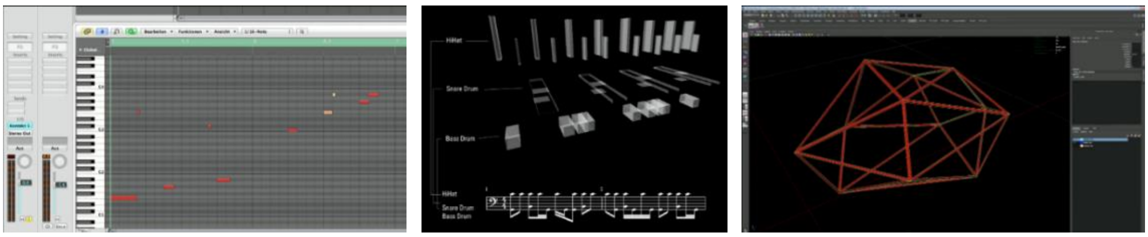

Figure 1. J.H. Hansen, The process of transforming music into form, 2012.

Figure 2. Hansen, J.H., My Song, 2009.

If music is used as a conceptual starting point, not only original designs could emerge, but also works that are not evaluated positively could be made by transferring the music directly into the design. In the study of Üstün and Kalaycı (2017), they argued that the direct connection with the musical elements was established in the façade design of the La Tourette Monastery designed by Le Corbusier and Iannis Xenakis, and this connection could not go beyond a visuality (Figure-3) (Üstün, Kalaycı, 2017). Accordingly, some approaches could be only visual as a result of transferring music into the design without abstraction. Original results could be obtained by reflecting the meaning of the music into the design rather than directly using the materials of the music.

Figure 3. Schapochnik, F., Le Corbusier and Iannis Xenakis, La Tourette Monastery, 1960.

Research Structure

It is important to benefit from different disciplines in basic design education in terms of giving students a new perspective. Music is one of the disciplines that has many common terms with architecture. There are numerous studies that investigate the use of music in architectural design education. In this section, these studies were examined by considering different approaches. Research data was collected using Google Scholar and Web of Science indexes and the studies were selected from the 2002 to 2018 time period (Table 2).

Table 2. Literature Research.

Area	Publication	Year	University	Department	Course	Method
Architecture / Basic Design Education	Maze, J.	2002	Florida University, USA	Architecture	Basic Design	Experiment
	Ham, J. J.	2005	Deakin University, Australia	Architecture	Architecture 2b	Experiment
	Khaled, M., Dewidar, K., Salama, H.A.	2008	-	-	-	Secondary Data Analysis, Experiment
	Yurtsever, B., Çakır, G.	2012	Karabük University, Turkey	Architecture	Basic Training, Architectural Studio I-II	Experiment
	Kuloğlu, N.	2015	Karadeniz Technical University, Turkey	Architecture	Basic Design Studio	Experiment
	Felix, M.N., Elsamahy, E.M.	2016	Beirut Arab University, Beirut	Architecture	-	Method Proposal
	Bostancı, B., Akbulak B., Akgül Y., E.	2016	Abant İzzet Baysal University, Turkey	Engineering and Architecture Faculty	Basic Design Studio I	Experiment
	Düzgün Bekdaş, H., Yıldız, S.	2018	Yıldız Technical University, Turkey	Architecture	Workshop	Experiment

"Musical Beginnings: Musings on Teaching with Music in the Fundamental Design Studio" J. Maze, 2002

The objective of Maze's (2002) study at the University of Florida is to develop basic design and interpretation skills through music before putting students directly into architectural design. Within the scope of the study, four strategies were implemented. In the first strategy, students were expected to design a 'Traditional Music Institute' by blending traditional Irish music and cultural heritage. In the second strategy, American minimal music was used as music material and they were asked to design with music through phonetic perception instead of notation examination. In this strategy, the ways in which students transfer the music they heard onto paper were observed. Students first made two-dimensional drawings and then produced three-dimensional models (Figure 4).

Figure 4. Maze, J., Strategy II, 2002.

In the third strategy, students were asked to design an instrument. The fourth strategy was created as a three-stage design approach. These were analysis, abstraction and production stages. The types of music used in the study were Traditional Irish Music, Cuban Music, American Jazz, Rock and Roll and European Classical Music. During the study, the selected music was analyzed and expressed in drawings. A three-dimensional model was produced by abstracting the analyzes. As a result of the study, it was observed that learning concepts such as composition, measure, layer, structure, rhythm improves abstract thinking ability before proceeding to building design.

"Music and Architecture: from Digital Composition to Physical Artifact" J. Ham, 2005

In the study conducted by Ham (2005) at Deakin University (Australia), as part of the second year design studio, the relationship between music and architecture was discussed through digital games and projects. The aim was to bring an interdisciplinary approach to the architectural education curriculum, which started to be computer oriented. Within the scope of the study, two different digital games were used for students to benefit from during the design process. The first of the games was made to reveal a work by identifying similar aspects of music and architecture disciplines in the composition and design process (Figure 5).

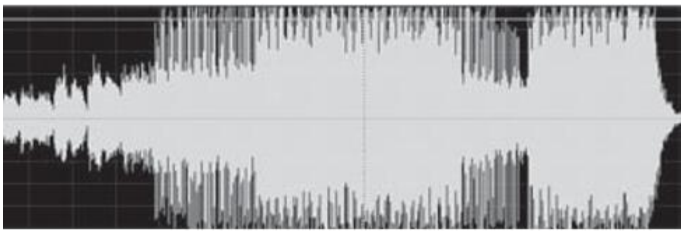

Figure 5. Ham, J.J., Digital composition of a student, 2005.

Half of the students examined the composition process of the musician, one-fourth created a digital music composition, and the remaining students designed a prototype musical instrument. The second game aimed to design architectural representations of musical works in a digital environment while focusing on the relationship between music and architecture. The musical works were selected by the students and architectural forms were created by considering the parameters of the music such as theme, rhythm and harmony (Figure 6).

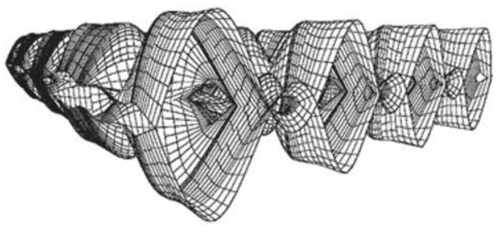

Figure 6. Ham, J.J., Digital composition of a student, 2005.

Students presented their designs as sketches, drawings, models and three-dimensional virtual models. Some of the works were selected to be applied to 1/1 scale (Figure 7). As a result of the study, it was determined that digital technologies are useful tools for the student to discover the relationship between music and architecture freely.

Figure 7. Ham, J.J., An example of the products, 2005.

"Mutual relation role between music and architecture in design development methods" K. M. Dewidar, M.N.A. Khaled & H. A. Salama, 2008

The study of Dewidar, Khaled and Salama (2008) is aimed to conduct a research in the context of using music as a new method for architecture. Therefore, they discussed the relationship between music and architecture in three steps. In the first step, the relationship between the two disciplines and the effect of the philosophical aspect of music on architecture were examined through examples. In the second step, the structures designed in three-dimensional drawing programs with music were analyzed. This section was divided into two, and in the first stage included the analysis of the structure named 'Paracube' by architect Marcos Novak. The design process of Novak was shown in four stages: 1- Organization of data and decision-making phase. 2- Numbers and algorithms. 3- Musical melodies. 4- Multiple surfaces and polygons. As a result of the examinations, it was determined that music could have an important role in creating a new method for architecture. The other half of the second step consists of student works. Students were asked to design a mixed structure that combines music performance and shopping functions (Figure 8). In the third step, the suitability of the new design approach arising from the relationship between music and architecture to society was discussed. Consequently, it was concluded that new architectural methods to be created with music unfortunately cannot be spread all over the world.

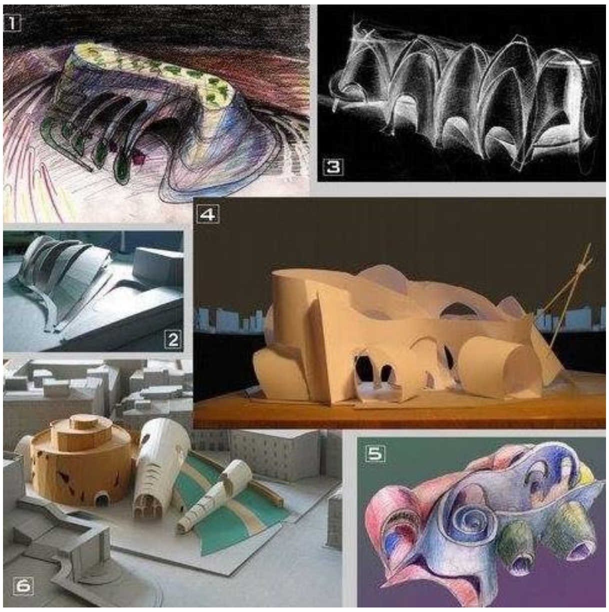

Figure 8. Dewidar, K. M., Khaled, M., Yossef, M. N. A, Salama, H. A., Results, 2005.

“An Assessment for interdisciplinary education modal implementation of basic design education in architecture” B. Yurtsever & G. Çakır, 2012

The aim of Yurtsever and Çakır's (2012) study at Karabük University (Turkey), was to bring an interdisciplinary approach to architectural education. In the study, they examined the relationship between music and design in the courses of Basic Education and Architectural Studio I-II. Firstly, students were asked to express themselves through a paper of 50x70 cm, and in the second stage, students were taught new forms of expression and human dimensions through painting. In the next step, students were asked to write the impressions they obtained from Vivaldi's “Four Seasons” concerto. At the last stage, students were asked to choose a solid color and they were expected to create a space by opening holes in their chosen color fabrics (Figure 9). As a result, it was observed that interdisciplinary studies improve students' abstract thinking ability and it was concluded that this approach could be applied in all parts of life, not only in architecture.

Figure 9. Üstün Özkan and Kalaycı, Results, 2005.

“Teaching Strategies Learning through Art: Music and Basic Design Education” N. Kuloğlu, 2014

In the study carried out by Kuloğlu (2014) at Karadeniz Technical University (Turkey), the similarities, common features and differences between music and architecture were examined and carried out with the tools that used in music and architecture within the Basic Design course. These tools of the two disciplines were investigated. Therefore, students were asked to design a music space using surfaces, with the effect that music had on them (Figure 10). As a result, it was determined that music can be used as a tool in design education.

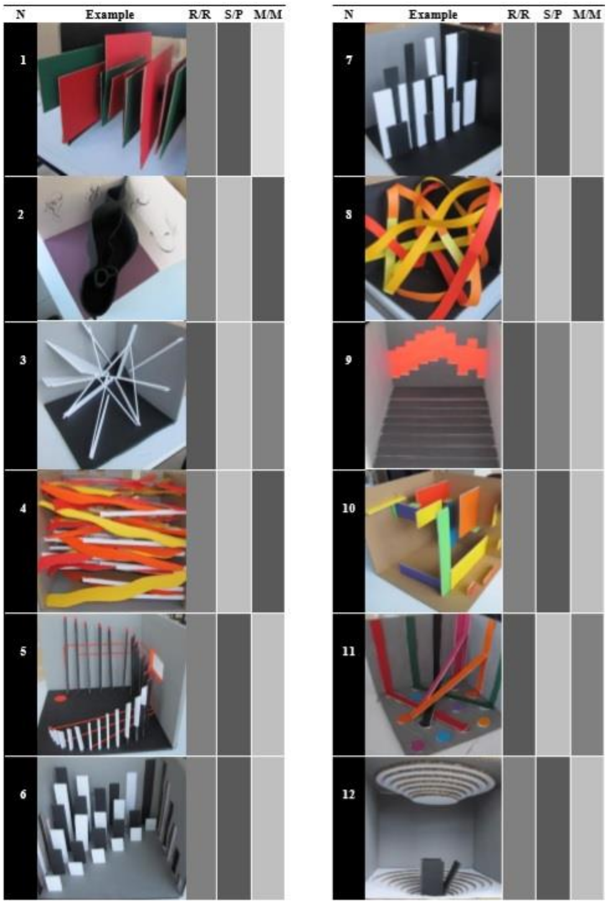

Figure 10. Kuloglu, N., Results, 2005.

"Visualizing Music Compositions in Architectural Conceptual Design" M. N. Felix & E. M. Elsamahy, 2016

The study carried out by Felix and Elsamahy (2016) at Beirut Arab University was conducted on common terminologies based on the creativity and design criteria of architecture and music. The aim of the study was to create a new conceptual thinking module in architectural education by including music in the design process. In the article, it was aimed to establish a relationship between the two disciplines by matching the structural components of music such as rhythm, melody, harmony with the architectural design levels which are plan, façade, structure, form and interior. Within the study, several approaches about the use of music in design were mentioned and one of them, "analysis of music layers and its effect on architectural form", was examined. This approach involved three stages: analysis, synthesis and evaluation. The first stage was the visualization of the music composition (Figure 11).

Figure 11. Felix, M. N., Elsamahy, E. M., The analyze of the music composition, 2016.

In the second stage, musical mapping was done by analyzing an architectural structure according to music principles and factors (Figure 12).

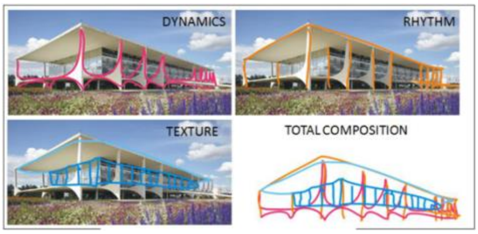

Figure 12. Felix, M. N., Elsamahy, E. M., Matching music concepts with architectural structures, 2016.

In the last stage, the façade of the building was successfully created by transforming the music layers into architectural forms (Figure 13).

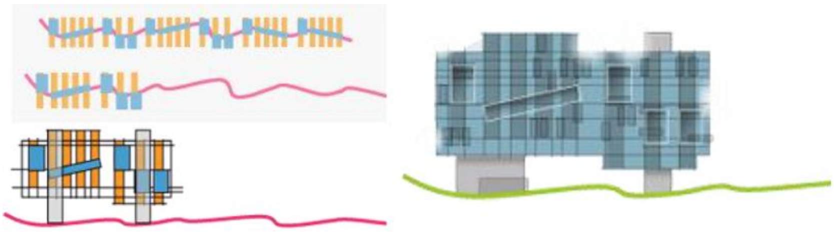

Figure 13. Felix, M. N., Elsamahy, E. M., Application of the method to façade design, 2016.

As a result of the study, it was determined that the relationship between music and architecture could bring an innovative approach to architectural education.

“The Tranformation of Music into Form: Basic Design Education in Architecture” B. Bostancı, B. Akbulak & E. Akgül Yalçın, 2016

In the study carried out by Bostancı, Akbulak and Yalçın (2017) at Abant İzzet Baysal University Faculty of Architecture (Turkey) in the Basic Design Studio-I course, it was aimed to perceive the basic concepts of design through music and applications in architectural education. Within the study, three different musical works were played to the students and asked to express their thoughts of these musical works in two and three dimensions. Selected musical works were: “Ljiouo” by Olafur Arnalds, “Nothing Else Matters” by Apocalyptica, and “Etude op. 25 no. 11” by Chopin. In the first stage of the study, students were asked to write what they felt by listening to the music and to express the music in two dimensions. In the second stage, they were expected to create a three-dimensional composition by using their drawings, with at least thirty pieces in one of the forms of triangle, square or circle. The results showed that the circle form for the "Ljiouo" (Figure 14), the square form for the "Nothing Else Matters" (Figure 15) and the triangular form for the "Etude op. 25 no. 11” (Figure 16) were the most chosen forms. As a result of the research, it was determined that music improves perception of composition elements in basic design or basic art education courses. During the study process, students learned about different approaches to establish interdisciplinary relationships.

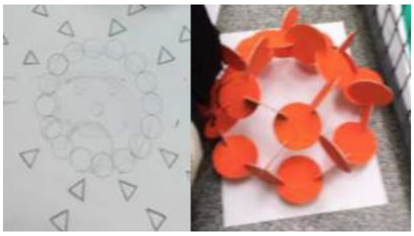

Figure 14. Bostancı, B., Akbulak, B., ***Ljiouo***, 2016.

Figure 15. Bostancı, B., Akbulak, B., ***Nothing Else Matters,*** 2016.

Figure 16. Bostancı, B., Akbulak, B., ***Etüde op.25 no.11,*** 2016.

"Conceptual Thinking at the Intersection of Art and Design: Informal Education Studies (2009–2015)" H. Düzgün Bektaş, S. Yıldız, 2018

The research of Düzgün Bekdaş and Yıldız (2018) conducted at Faculty of Architecture of Yıldız Technical University (Turkey) were focused on the workshops such as "Music-Design", "Literature-Design" and "Art-Design". In the study, it was aimed to develop the benefits of holistic approaches and design thinking methods in the initial phase of the design process. In the Music-Design workshop, students were expected to present their musical works visually. Therefore, it was observed that different emotions created by different musical works are transferred to objects with various approaches. Furthermore, two different musical pieces were played to students, and they were asked to visualize the emotions they felt. The subjective and objective concepts that emerged were brought together and turned into works (Figure 17). As a result, it was observed that combining different art branches with design benefits the development of actions such as analysis, synthesis, abstraction, correlation, interpretation and communication. It was concluded that interdisciplinary studies in the field of design will increase the diversity of approaches in terms of creativity in architecture.

Figure 17. **Düzgün Bekdaş, H., Yıldız, S., Music-Design Workshop, 2018.**

Results and Discussion

The studies (8) selected for this paper have aimed to evaluate music as an interdisciplinary approach in architecture education. Amongst the studies, three of them were carried out in a first-year basic design studio, one was carried out in a second-year architectural design studio, one was carried out in both first-year basic design and second-year architectural design studios, and one was a workshop. Seven were experimental and the remaining one was a method proposal. In five of these experimental studies, students were given a brief and asked to use selected tools or musical works, in the remaining two, students were not restricted with tools or selected music. The studies aimed to bring a new interdisciplinary approach in architecture education in order to improve creativity. Their results were mutual, and it was found that music is a creative tool in basic architectural education and this interdisciplinary approach increases abstract thinking and creativity.

The study of Maze (2002) was carried out with four different strategic approaches that included music in design. Different approaches used in this study increased the variety of creative performance. In particular, it was shown that the instrument design strategy could give architecture students a different perspective.

The study of Ham (2005) was based on the use of music in design process via two digital games. Combining digital games with music in order to create architectural forms was an exciting idea. In this way, students were able to discover the possibilities of using music in design.

The study of Dewidar, Khaled and Salama (2008) was a research in the use of music in architecture as a new method for architectural design. In this study, the use of music in architecture was pointed out. The analysis strategies proposed are considerable.

The study of Yurtsever and Çakır (2012) was conducted by first expressing the feelings of selected musical work in two dimensions and then transforming these expressions into space design using fabrics and solid colors. In the study, students were asked to cut the fabrics and design a space with them. The study showed that interdisciplinary approaches increased the ability of abstract thinking. There would be diversity of creative form creations, if students were allowed to use a variety of tools and materials other than that given them.

The study of Kuloğlu (2014) was based on the use of music's phonetic effect in the design process. In this study, students were asked to investigate the similarities between music and architecture, then were asked to design forms with the music's phonetic effect by using a variety of surfaces. The purpose of using these surfaces was unclear and the initial method description which pointed out the similarities between two disciplines, has not matched with the final experiment.

The study of Felix and Elsamahy (2016) was based on creating a new conceptual design method in architectural education by including music in the design process. It was found that the method proposed in this study, not only could be a creative thinking method but also could lead to design without proper consideration. Analyzing and reflecting music compositions into the design would bring predictable approaches as in the ‘La Tourette Monastery’ example mentioned in the introduction of this article.

The study of Bostancı, Akbulak and Yalçın (2017) was conducted to create abstract forms by listening to selected music using simple geometric forms. In this study, students were asked to design with music by using certain forms, but it resulted in similar outcomes even if they were used different music.

The study of Düzgün Bekdaş and Yıldız (2018) was based on visualizing feelings of the musical works. In the music-design workshop, music was only visualized in two dimensions. It is concluded that the interdisciplinary approaches increase the creativity. Continuing the study with three-dimensional forms could enable students to get a better understanding of the relationship between design and music.

This article aims to examine existing studies about the use of music in architecture education. For this purpose, eight bibliographic studies on the relationship between music and architecture are examined. The common point of these articles is that designing with music gives students a different and creative perspective. It was mutually observed that unique products emerged in line with each student's different perception of music. In conclusion, it is found that music is a creative tool for design and the new approach proposals combining music and design benefited architectural design education.

Creating forms with music is beneficial to students as a practice in the learning process of design. In the selected studies, it is seen that music is a creative tool in early design education. Also, the examples of buildings designed with music show that music and design relationships are creative and innovative approaches in the architecture field.

If students design the whole architectural project with music, this could be an innovative approach to connect the architectural project with an art discipline and create a different conceptual work. In the examined studies, music is used in creating basic architectural forms. Furthermore, in architectural education, students could be encouraged to use music as a conceptual starting point for the entire project in a holistic approach, and it could be a product, a space or a building. They could use music in the entire architectural project from space to façade. In this approach, music would not be the only factor, but one of many. A lot of meaning can be derived from a musical work and these meanings can be matched with different concepts. This could increase the variety of creative results and give students different perspectives. Students could learn many different approaches to design a project while creating connections between musical meanings and concepts. This approach could expand the perspective of using music in architectural design education. In further studies, a method of designing with music will be investigated.

In addition, there are many common terms between architecture and music such as rhythm, ratio-proportion, harmony. These similarities lay the groundwork for the two disciplines to work together. In this context, the relationship between music and architecture can also be mutual. Music can be inspired by architecture. On both sides, designers and musicians can work together. This can also be a subject for further studies.

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Book Review: Reflections on Technology for Educational Practitioners

Dakers, J. R., Hallström, J., & de Vries, M. J. (Eds.). (2019). *Reflections on Technology for Educational Practitioners*. Leiden: Brill | Sense. https://doi.org/10.1163/9789004405516

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Introduction

Reflections on Technology for Educational Practitioners is a valuable addition to the growing body of knowledge for technology education. This book takes an in-depth look at the philosophy of technology, and how this could contribute to understanding of the very nature of technology, particularly in support of curriculum writers, teachers and researchers in the technology education community. The underlying assumption of this book is that the philosophy of technology has value for technology education. Each chapter is written by a prominent technology education figure who discusses a specific philosopher of technology and how their ideas could be incorporated by practitioners.

The structure of the fourteen chapters is similar. The author introduces the philosopher and gives a biographical sketch of the person and their work. This is followed by an overview of the contribution they made to the philosophy of technology, in terms of specific frameworks, concepts or approaches. Finally, each chapter ends with a section in which the authors describe the relevance of the philosophers' contribution to the technology education community. These contributions vary; some focus on the value of educational research from specific frameworks, while others are more practical and suggest topics and activities for the technology classroom. Some authors chose to focus on specific teaching strategies such as questioning and critiquing or specific knowledge types to include in a technology curriculum. Most of the chapters provide practical examples showing the incorporation of these philosophical views into practice, while others ask questions to stimulate individual reflection and the development of future action plans to redefine how technology education should be enacted.

Chapter overviews

Chapter 1 – Introduction

John Dakers, Jonas Hallström, Marc de Vries

In the introduction, the editors, Dakers, Hallström and de Vries explain the usefulness of the philosophy of technology for the technology education community and provide an overview of the analytical and continental traditions of philosophy, including the differences between them. The editors also identify some of the major themes that are addressed in each chapter, using Mitcham's (1994) typology of technology. The introductory chapter ends with short descriptions of each chapter, giving some biographical information on each of the philosophers as discussed in the chapters.

Chapter 2: Carl Mitcham: Descriptions of Technology
Johan Svenningson

In his description of the work of Carl Mitcham, Svenningson describes the nature of Mitcham's thinking by detailing the four ways in which technology is manifested as knowledge, volition, activities and objects, thus outlining a conceptual framework of the different conceptualisations of technology. In demonstrating the usefulness of Mitcham's typology of technology for research in technology education, Svenningson designed and implemented a pilot study that was conducted in Sweden with 13 to 14 year old students, to explore students' descriptions of technology. In doing so, Svenningson developed the Mitcham score to classify the broadness of students' descriptions of technology. Svenningson found that by using Mitcham's typology and the Mitcham score, researchers and teachers could gain an overview of a class's technological awareness which may ameliorate the design of technology lessons.

Chapter 3: Peter Kroes and Anthonie Meijers: The Dual Nature of Artefacts
Marc de Vries

In the first part of the chapter, de Vries discusses the development of analytical philosophy, a benefit of which is to reduce complex issues to their basics. In light of this, the dual nature of technical artefacts, viz the physical and functional nature, is introduced and discussed as a way to reduce the complexity of technological artefacts. De Vries also demonstrates how such a view of artefacts has implications for our understanding of technological knowledge, technological design and the ethical and moral underpinnings of technology. In demonstrating the usefulness and relevance of Kroes and Meier's dual nature of artefacts framework, de Vries reports on three applications of this framework for the purposes of curriculum development, investigating teachers' understanding of artefacts and developing students' understanding of technology. De Vries ends off the chapter by emphasising the value of using analytical philosophy frameworks as they help to conceptualise the nature of reality at basic levels.

Chapter 4: Günter Rophohl: Supporting Technological Literacy for Future Citizenship
Vicky Compton

Compton starts the chapter by introducing Ropohl as a German philosopher of technology who held a systems view of technology. This view characterises his contributions to the philosophy of technology, which subsequently informed the conceptualization and development of the New Zealand Technology Education curriculum. In discussing Ropohl's work, Compton highlights four specific contributions Ropohl made to the philosophy of technology, namely, his description of the features of technology that distinguish it from science, his classification of the different types of technological knowledge, an analysis of artefacts as socio-technical systems, and the formulation of ethics and responsibilities of engineers. In outlining each of these contributions, Compton provides valuable insights to support each of these contributions' relevance for technology education. In the final part of the chapter, Compton outlines the relationships between Ropohl's ideas and the embedded curriculum strands and components in the New Zealand Technology curriculum, and finalizes the chapter by reporting on the benefits of this approach for student learning.

Chapter 5 – Pierre Rabardel: Instrumented Activity and Theory of Instrument

Marjolaine Chatoney and Patrice Laisney

Chatoney and Laisney discuss the focus of Rabardel's philosophy in terms of the relationships between humans, technological objects and technical systems. In particular, they elaborate on Rabardel's theory of instrumental genesis and how this influences the cognitive development of humans. This provides a range of tools and concepts to analyse the nature of human beings' goal-directed behavior as they engage with technologies in specific contexts. Chatoney and Laisney demonstrate the usefulness of Rabardel's theory of instrumented action in analysing the way in which students designed a protective cover for a smartphone using instruments including digital and analogue drawings and a 3D printer. They conclude that Rabardel's philosophy allowed them to reveal the different ways in which students' goal-directed activities evolved as they interacted with different artefacts. Important results are discussed pertaining to the role of drawings, CAD and 3D printing during solution conceptualization.

Chapter 6: Gilbert Simondon: On the Mode of Existence of Technical Objects in Technology Education

John Dakers

In this chapter, Dakers discusses Simondon's concept of 'individuation' which refers to the processes that explain the coming into being of everything: material, organic, social and technical. These processes are viewed as phase shifts by Simondon and imply that technical objects go through many evolutions or phase shifts and thus do not exist in isolation, i.e. each phase carries the implication of a preceding phase. In terms of technology education, Dakers refers to Simondon's idea of 'genetic pedagogy', which requires that account be taken of the general evolution of artefacts with their components and the socio-technical contexts in which they developed, resulting in the artefacts we are familiar with today. Dakers is of the opinion that such an approach to technology education could eliminate reductive subject/object, academic/vocational and thought/action dualities and enable new ways of understanding how new technical objects may emerge from existing realities.

Dakers also reports on Simondon's ideas about the nature of the relations and the major and minor rapport between humans and technical artefacts. A minor aspect is related to technical knowledge and that which is implicit and even habitual. The major aspect, by contrast, involves reflection and self-awareness. Simondon likens this to the difference in knowledge between the apprentice and the engineer. Dakers agrees with Simondon that current Technology Education curricula deals predominantly with minor technics, while the major technics are often kept for the more able child and adult. Simondon sees information theory as the resolution of this dichotomy. Ending this chapter, Dakers draws together the significant threads of Simondon's philosophical stance by presenting a strategy for introducing learners to technologies, forming the basis of individuation. Ultimately, it is hoped that the craftsman and the engineer can be reconciled through a milieu that emphasizes that which is human and democratic.

Chapter 7 Bernard Stiegler: On the Origin of the Relationship between Technology and Humans

John Dakers

In this chapter, Dakers explores Stiegler's ideas on the co-evolutionary processes that are involved between humans and technology. In contrast to philosophers such as Rousseau and Spengler, Stiegler did not believe that humans were born as 'complete' beings, but only in their interactions with technology did they develop the ability to walk upright, grasp objects and communicate, which led to the development of their psychomotor, intellectual and inventive capacities. In this way, as humans invent their technology, the technology invents the human. Dakers is of the opinion that the ideas of these co-evolutionary processes are lacking in current technology education curricula. Dakers argues that, instead of focusing on the development of technological literacy, technology education emphasises the craft-oriented aspects of technology. The chapter ends with Dakers advocating for education about technology, specifically understanding the human-technology relationship and the effect thereof on human life.

Chapter 8 Bruno Latour: Actor Network Theory

John Dakers

In this chapter, Dakers discusses Latour's Actor Network Theory (ANT) in order to present an alternative way of conceptualizing pedagogy and curriculum design in technology education. The first part of the chapter is dedicated to the exploration of such terms as 'actors', 'agency', and networks and how these concepts build on the previous work of Simondon and Stiegler. The second part of the chapter uses the concepts from ANT to look at current challenges in technology education, with the aim of reconceptualising teaching and learning in technology education. Although Dakers acknowledges that ANT does not provide guidelines for pedagogy or curriculum design, he does propose that the activity of curriculum design should be re-evaluated. Less emphasis should be placed on writing universal, prescriptive plans, allowing emergent learning to occur as actors in a technology classroom interact with each other. In this way, lesson planning should be seen as more open-ended, involving writing lesson guides as opposed to prescriptive lesson plans. Dakers also identifies an opportunity for researchers to use ANT as a framework to investigate new models for the delivery of technology education.

Chapter 9: Andrew Feenberg: Implications of Critical Theory for Technology Education

Piet Ankiewicz

In Chapter 9, Ankiewicz discusses Andrew Feenberg's critical theory of technology. In particular, he describes Feenberg's instrumentalization theory as an important contribution to the philosophy of technology. Instrumentalization theory allows philosophers to analyse artefacts on two levels. On one level, artefacts can be analysed in terms of their technical elements, devoid of any use context (primary instrumentalization), and on the other level, artefacts could be analyzed in terms of the secondary instrumentalization. Secondary instrumentalization refers to the causal interconnections between the technical components themselves and the artefact's links with the social and natural environment (systemization), as well as the various social constraints under which technical artefacts may be integrated into society (mediations). In this way, society has some input into the design of technology. It is this input in which human beings may have some control over technological development. In discussing the implications of Feenberg's philosophy for technology education, Ankiewicz highlights the need for emphasizing values, based on Feenberg's notion of technical codes. Doing this could help develop students' ability to justify their design and manufacturing choices in terms of their personal and societal values.

Chapter 10 Langdon Winner: A Call for a Critical Philosophy of Technology

Cecilia Axell

This chapter by Axell continues to emphasise the importance of developing a critical philosophy of technology. In providing an overview of Winner's critical philosophy of technology, Axell highlights Winners' notion of technologies as forms of life and the fact that artefacts are value-laden and in most cases, embody political aspects. Axell highlights Winners' descriptions of the difference between democratic and authoritarian technics, with the view to advocate for decentralized and democratic politics of technology. In this way, power is distributed to not only expert designers and people in power, but also to non-designers who should be able to take part in decision making and have informed opinions about the social, cultural, political, natural and market contexts in which technologies develop. At the heart of democratic technics lies the idea that technologies should be more accessible, comprehensible and controllable. Axell establishes the relevance of Winners' contribution to the philosophy of technology by outlining the foundations of a critical pedagogy of technology education. In such a pedagogy, the importance of developing critical thinking beyond what happens in design and make activities is stressed. To this end, Winners' idea of forms of life should be used to facilitate learners' attention to the potential benefits and risks of past, present and future technologies with a specific focus on the winners and losers from multiple perspectives.

Chapter 11: Kevin Kelly: Technology Education for the Technium

David Barlex

In this chapter, Barlex explores Kevin Kelly's idea of technology as a conglomeration of individual technologies, linked together in an overall system called the 'technium'. How the technium develops is depended on three forces, namely pre-ordained development, the influence of technological history and society's free will. Barlex explores Kelly's view in noting that these forces actually restrict the influence that humans can have on technological developments. Specifically, Barlex identifies a limitation in Kelly's writings in that they do not account for the role of capitalism in technological developments and that humans only really have an influence at the beginning of technological developments. In relating Kelly's ideas of technology to technology education, Barlex emphasizes the need for developing students' technological perspectives and uses the 'tetrahedron approach' to demonstrate how teachers could incorporate Kelly's ideas into their technology lessons. In demonstrating such a lesson practically, Barlex use the 'wicked' problem of sustainable transport and the development of autonomous electrical vehicles as a context to develop both students' technological perspectives and their technological capability. Using Kelly's work, Barlex claims that a more equitable balance between technological perspectives and technological capability in the technology curriculum could be restored.

Chapter 12 Don Ihde: Praxis Philosophies and Design and Technology Education

Steve Keirl

Before discussing Idhe's contributions to the philosophy of technology, Keirl gives an overview of the philosophical landscape underpinning Idhe's contributions. Concepts such as post-phenomenology, pragmatism, hermeneutics, intentionality and life world are explained in detail, which provides a bridge for the reader to understand Idhe's writings. Keirl then outlines some of Idhe's areas of foci, including technology-science relations, technology and the life world, technology relations and 'Our life world', cultural hermeneutics, the designer fallacy, bodies in technology and the notion of posthumanity. All of these foci reveal insight and different perspectives of human-technology-society-environment interactions, which could augment and enrich how we approach the development of technological literacy in education. Before relating Idhe's work to technology education, Keirl reflects on the current challenges faced by the education system in general, specifically the current 'western-style' of education where knowledge is seen as identifiable, quantifiable, teachable and assessable and the purpose of education is related to capitalist values. In order to envisage the realisation of Idhe's technological world in classrooms, Keirl foregrounds the concept of technological literacy and proposes three ways in which this could happen as well as some of the immediate advantages for curriculum and pedagogy. Keirl finishes the chapter by challenging the technology education community to find ways in which we could educate students about technology's roles in our lifeworlds by using Idhe's work.

Chapter 13: Albert Borgmann: The Device Paradigm

John Dakers and Marc de Vries

Dakers and de Vries start the chapter by providing a brief overview of dystopian philosophers of technology, in particular Borgmann, who expresses concern about the interrelationship between humans, technology and the natural environment. Dakers and de Vries believe that reflecting on these views is valuable for technology education as it could afford a balanced approach toward the development of technological literacy. Dakers and de Vries report on two of Borgmann's contributions, namely his notion of the device paradigm, and his theory of focal things and practices. Essentially, the device paradigm refers to the way technologies commodify activities, causing disembodied and disengaged human beings, while focal things and practices refer to activities that lead to deeper and meaningful engagements with society and the environment. Relating Borgmann's contribution to technology education, Dakers and de Vries recommend that Borgmann's theory of focal things and practices be used as a structure to guide explorations, debates and discussions on how technologies can better enhance contemporary life by designing a more meaningful future, while critiquing the activities that make society disconnected.

Chapter 14: Clive Staples Lewis: Social, Environmental and Biomedical Implications of Technology

Jonas Hallström

In the final chapter, Hallström explores the implications of The Abolition of Man, by C.S Lewis, for the philosophy of technology. Hallström identifies three themes in Lewis' work, namely his views on social, environmental and biomedical effects of technology. Importantly, he notes that Lewis' work goes beyond the usual critiques of technology, by including reflections on human and moral dimensions underpinning the effects of technology. Hallström points out that the implications of Lewis' work for technology are two-fold: teachers should focus on the connections and interactions between social and environmental issues when talking about the implications of technology, and teachers should engage students in ethical questioning and critiquing of future scenarios.

Strengths and weaknesses

The authors frequently allude to the interconnectedness between the concepts and ideas of the different philosophers in their respective chapters. While some of the chapters are written with density that does not make for easy reading, as a general rule the book is lucid and accessible. Although some authors refer to the usefulness of the philosophies that are discussed in this book, this book would particularly appeal to the academic.

While I appreciate the emphasis on the relationship between technology, society and the natural environment in Chapters 5 to 14, I do however miss a nod in the direction of philosophies related to graphicacy, the nature of modelling and design methodology. This might be the subject of future volumes. It might also be interesting to explore Eastern and African philosophies of technology in future volumes.

Despite infrequent technical errors, this book demonstrates an erudition and deep insight into philosophies that are pivotal for enriching technology education practices. I look forward with anticipation to future volumes that will continue in the standard of excellence established in this book.

Overall conclusion

In conclusion, the book contains a wealth of insights from the philosophy of technology that could augment and enrich practitioners' views of technology education. *Reflections on Technology for Educational Practitioners* is a valuable resource for those interested in exploring the theoretical underpinnings of technology education, and can offer new ways for practitioners to think about how they teach, write or conduct research into technology and technology education. This book provides useful and timely questions, guidelines and reflections on the philosophy of technology and its role in enhancing technology education practices.